DIRC-based PID for the EIC

— Progress Report and Renewal Proposal

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Generic Detector R&D for an Electron Ion Collider

Advisory Committee Meeting, BNL, July 21, 2014

Outline

1. Introduction

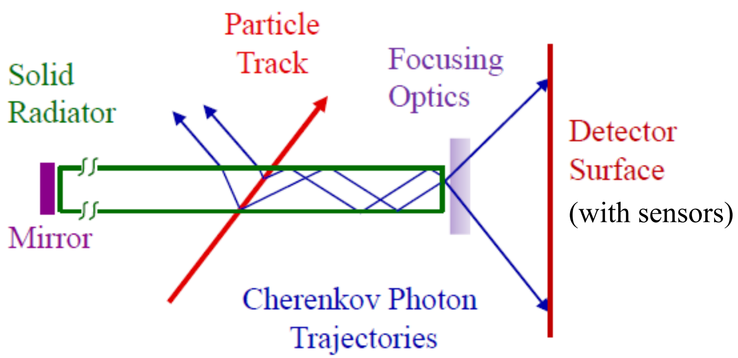
2. DIRC simulations and beam tests

3. High-B field test facility

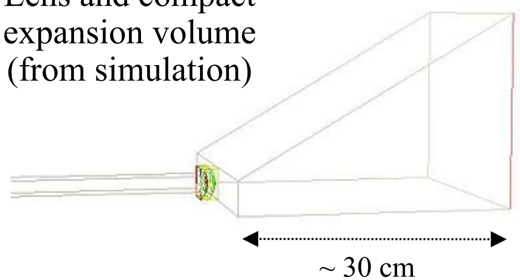
DIRC summary

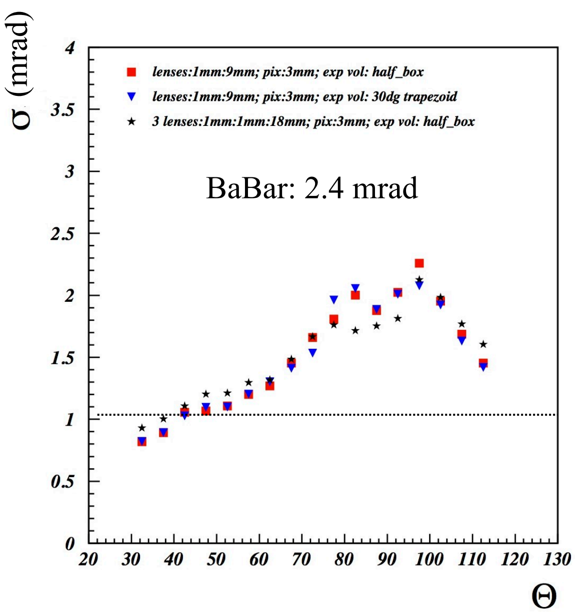
- A DIRC can provide a radially compact particle identification solution for the EIC central detector
- The goals of this R&D are to adapt the DIRC technology to the EIC requirements (performance and integration)
- Simulations show that using novel lenses and a compact expansion volume one could improve the resolution at forward angles below 1 mrad, corresponding to a 3σ K/π separation at 6 GeV/c (and greater at lower momenta)

General layout of a DIRC with lens focusing

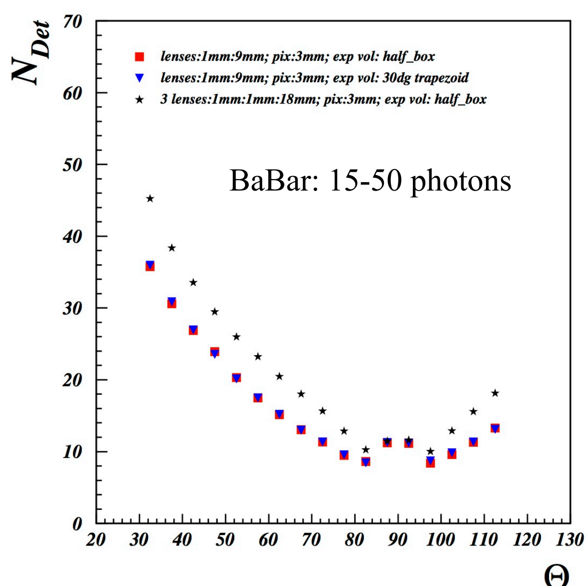


Lens and compact expansion volume (from simulation)

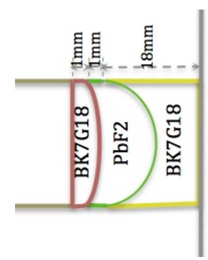




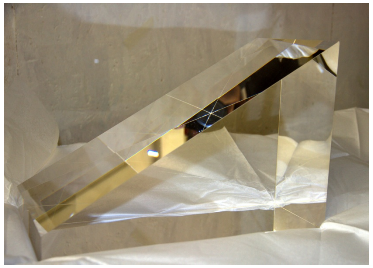
Simulated Cherenkov angle resolution (for each track)



Simulated Cherenkov photon number

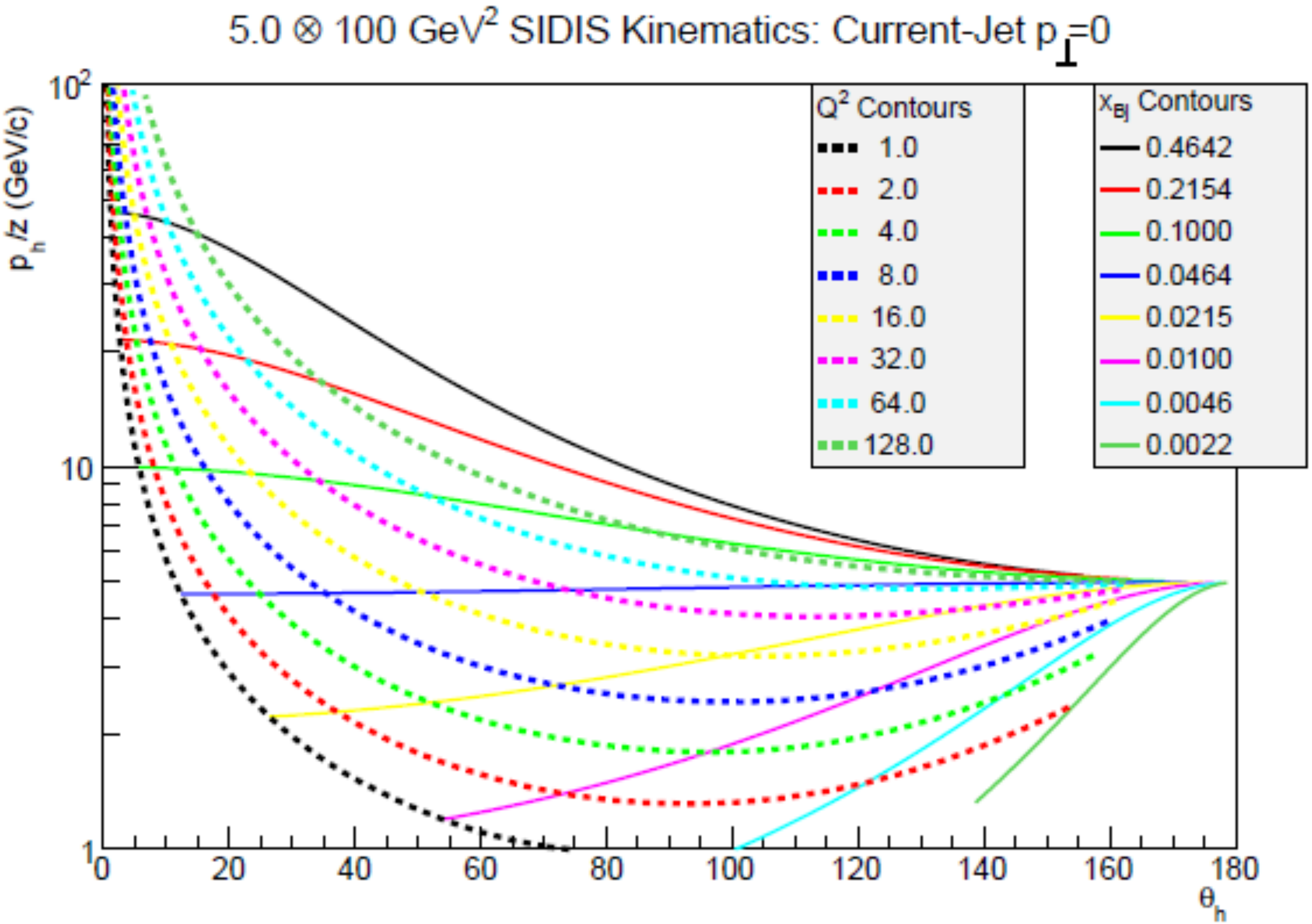


Novel high index of refraction lens (no air gaps)



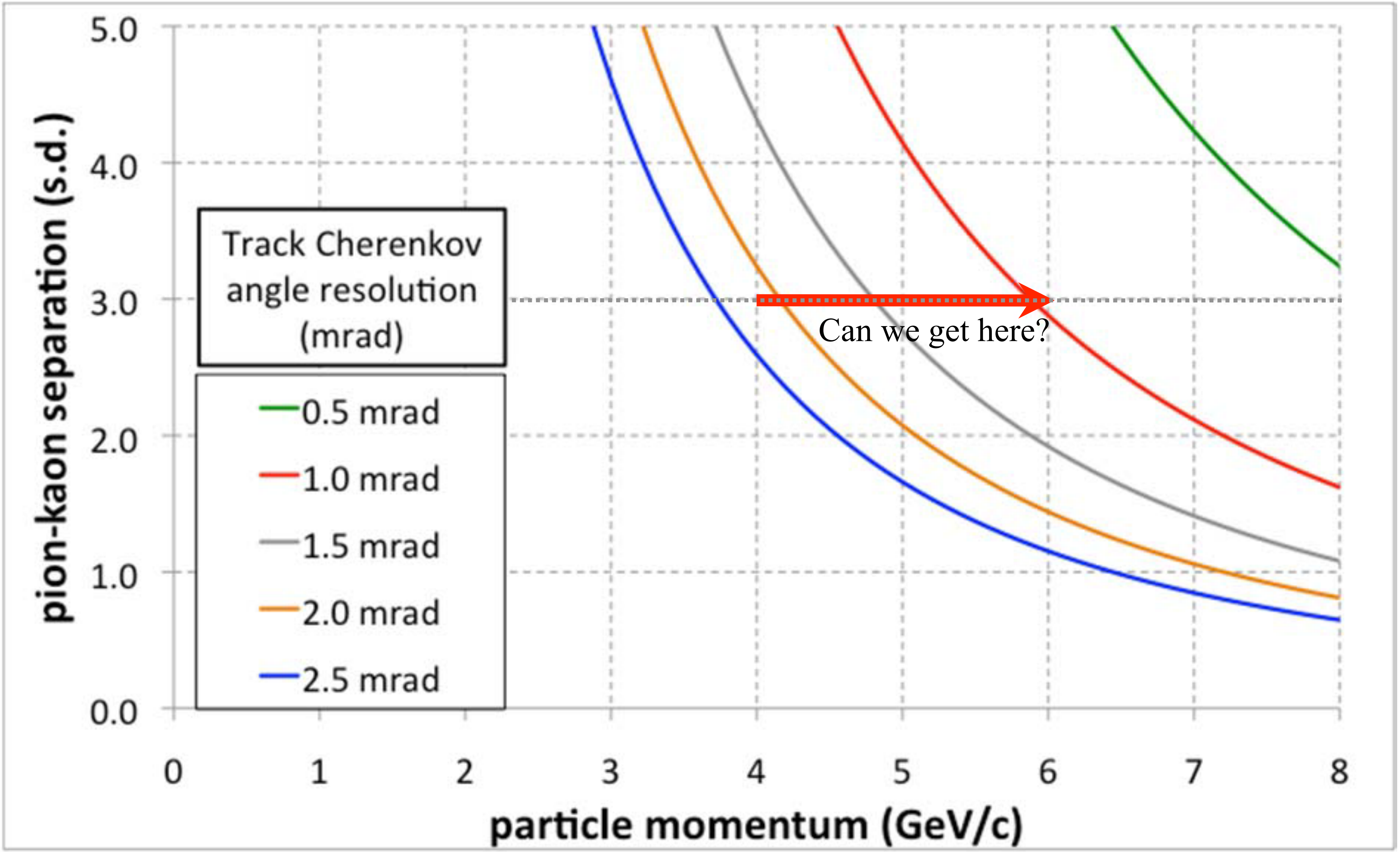
Compact expansion volume of fuzed silica (quartz)

Example: π/K identification in semi-inclusive DIS



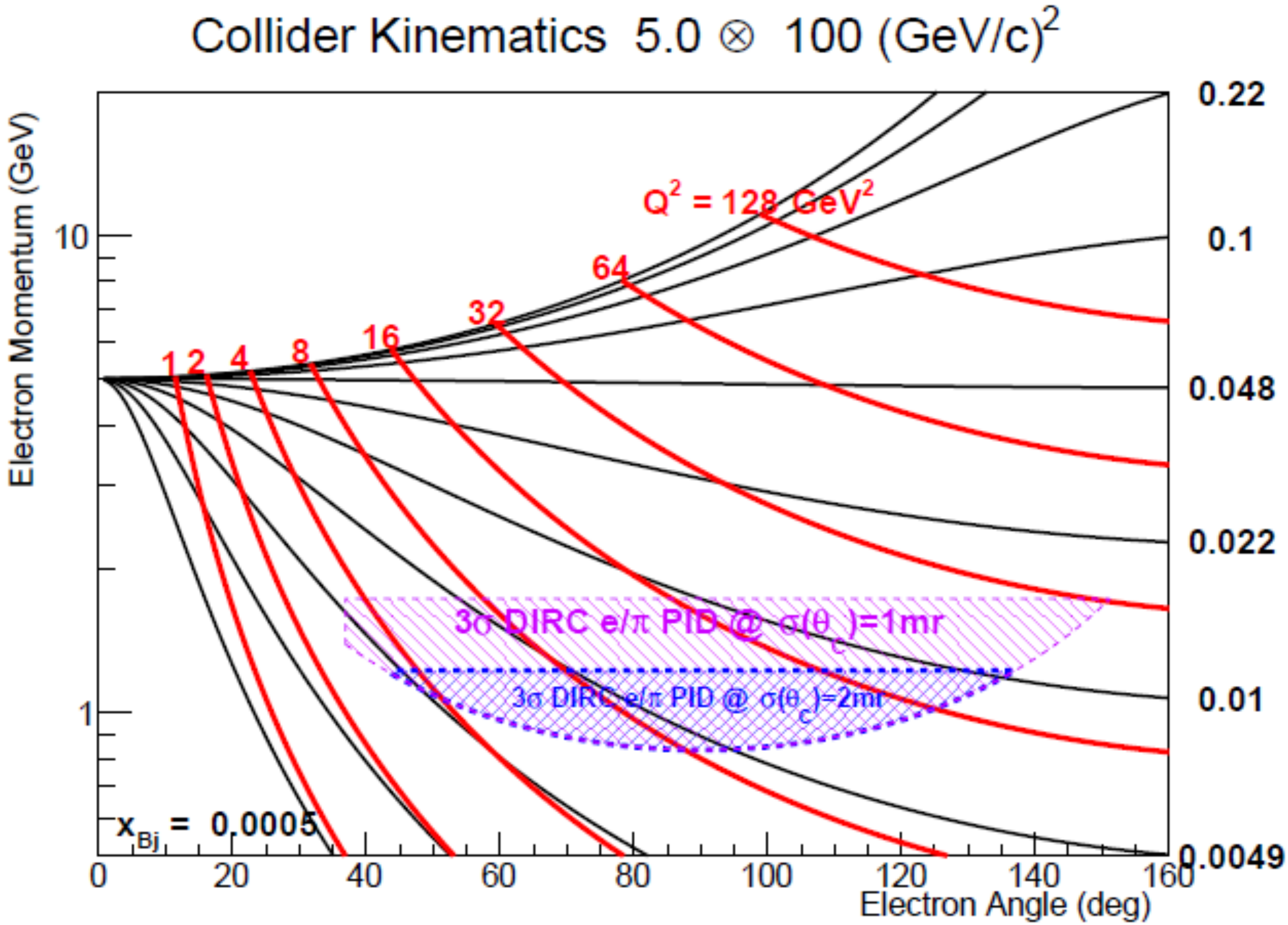
- Need high momentum coverage – especially at forward barrel angles!

π/K ID as a function of the θ_c resolution



- Proof-of-concept simulations suggest possible to reach 6 GeV/c at forward angles

Example: e/π identification in DIS at low x



- High-Q^2, low-x electrons have low momenta and require good pion suppression

Improving the θ_c resolution

$$\sigma_{\theta_c}^{track} = \frac{\sigma_{\theta_c}^{photon}}{\sqrt{N_{p.e.}}} \otimes \sigma^{correlated}$$

Correlated term:
tracking detectors, multiple scattering, etc

$$\sigma_{\theta_c}^{photon} = \sqrt{\sigma_{bar-size}^2 + \sigma_{pixel-size}^2 + \sigma_{chromatic}^2 + \sigma_{bar-imperfection}^2}$$

BABAR-DIRC Cherenkov angle resolution: 9.6 mrad per photon → 2.4 mrad per track

Limited in BABAR by:			Could be improved via:
· size of bar image	~4.1 mrad	→	· focusing optics
· size of PMT pixel	~5.5 mrad	→	· smaller pixel size
· chromaticity ($n=n(\lambda)$)	~5.4 mrad	→	· better time resolution
	9.6 mrad	→	4-5 mrad (?) per photon
· number of photons	15-50	→	· photocathode/SiPM

topics for R&D proposal

- DIRC bar thickness can in principle also be increased beyond the 17 mm (19% r.l.) used in Babar
- Excellent 3D imaging (2 spatial + time) essential for pushing performance beyond state-of-the-art

R&D goals and progress summary

1. Investigate possibility of pushing state-of-the-art performance

- Extend 3σ π/K separation beyond 4 GeV/c, maybe as high as 6 GeV/c
  - also improves e/π and K/p separation

Accomplished. Proof of concept simulations done! Simulations being verified

2. Demonstrate feasibility of using a DIRC in the EIC detector

- Compact readout "camera" (focusing + expansion volume + sensors)
  - simulations, lens and EV design, prototyping, test beams
- Operation in high magnetic fields (up to 3 T)
  - sensor tests up to 5T

Ongoing. Lots of progress!

High-B facility is set up and ready!

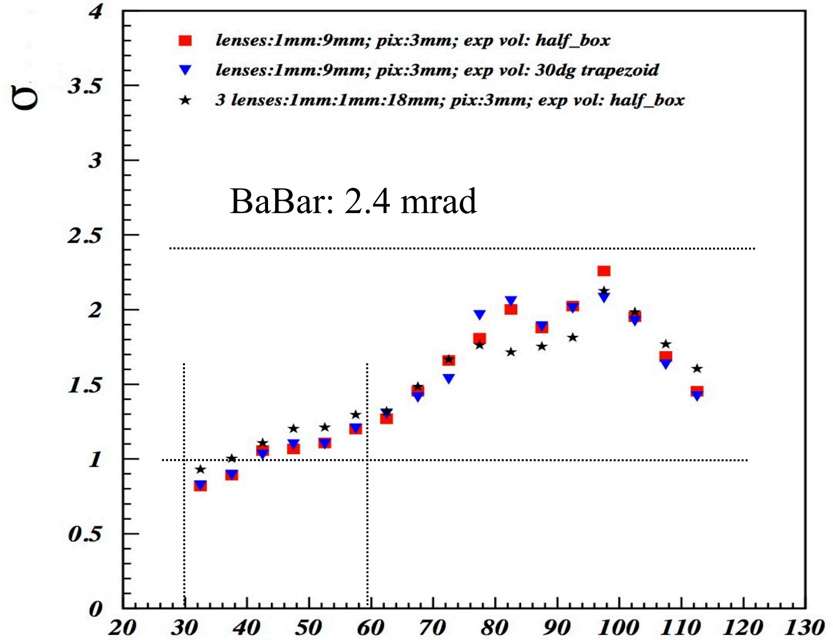
3. Study integration of the DIRC with other detector systems

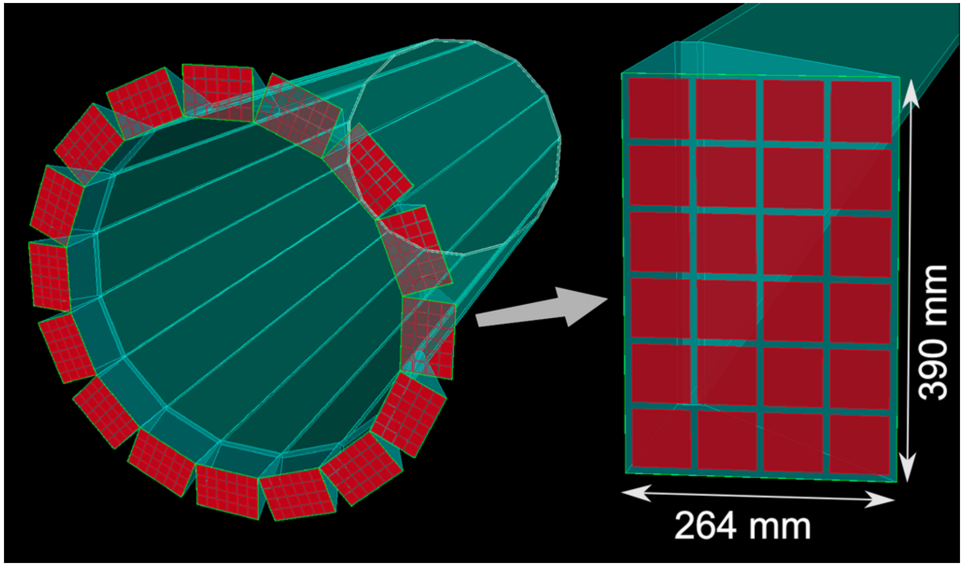
- Supplementary Cherekov? Internal or external readout? Bars or plates?
- Impact on endcap design and barrel calorimeter? New configurations?

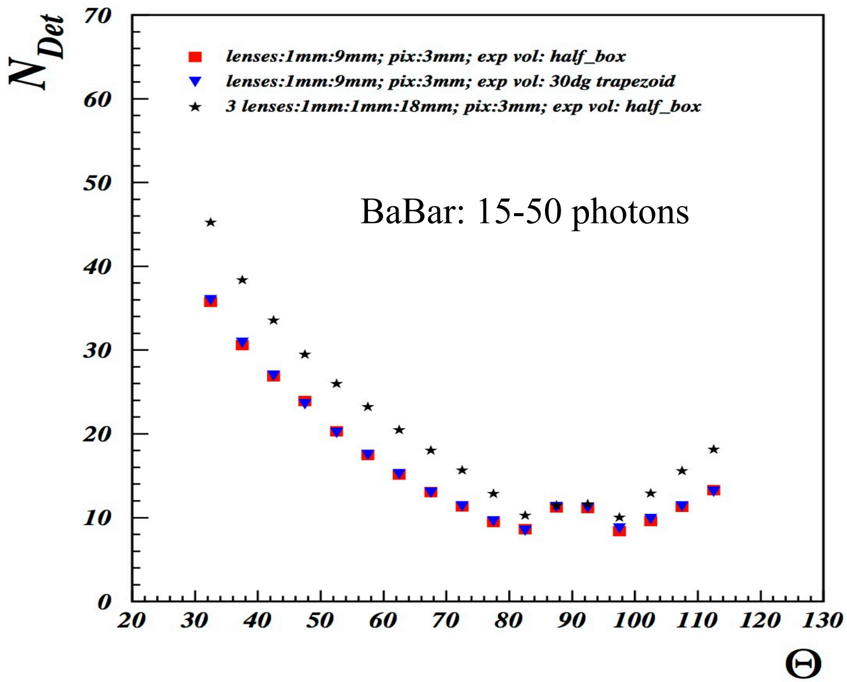
Some progress

Remains to be done, but also new questions

Verifying θ_c resolution obtained in simulation





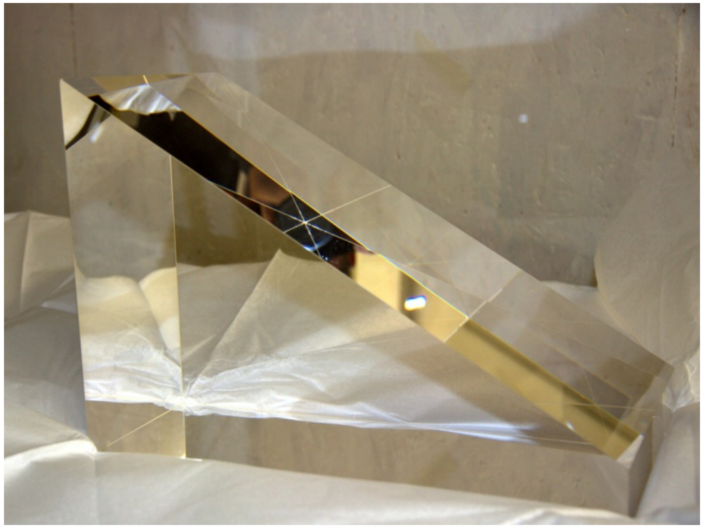


- Proof-of-concept simulations by first ODU postdoc H. Seraydaryan showed that 1 mrad θ_c resolution (per track, i.e., including all photons) was possible at forward angles

- To check this result, G. Kalicy (new ODU postdoc) is redoing the ray-tracing simulations using a different reconstruction package, and R. Dzhygadlo (new member from GSI) is helping to set up a GEANT4 simulation (shown above).

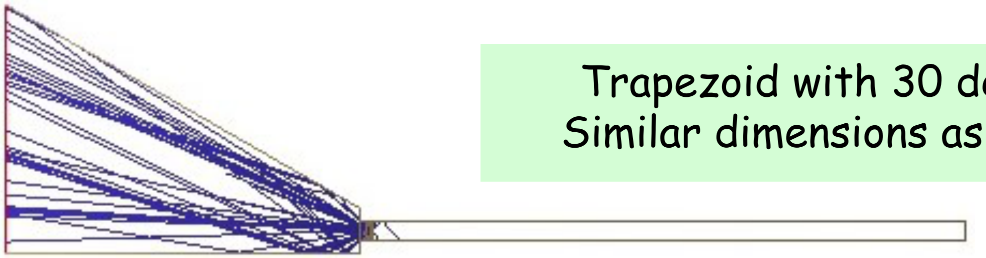
- After this, simulations will continue to include new lens- and EV configurations

Expansion volume geometries

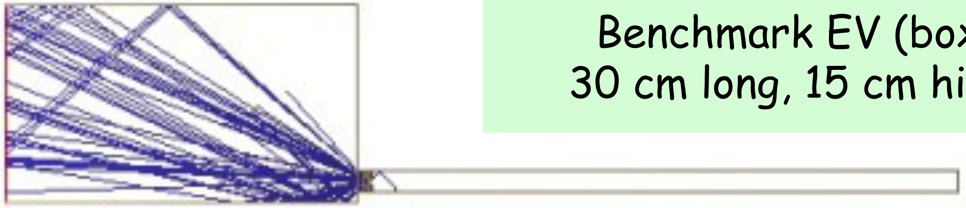


One of two fused silica EVs now available at GSI

- Initial simulations were performed for two benchmark geometries: box and trapezoid
- Trapezoid matches 30 cm long EVs available through synergies with GSI R&D.
  - Excellent opportunity for developing optics
- Once optics development is complete, an expansion volume matching the focal plane will be developed
  - Interplay between pixel size and sensor placement close to focal plane?



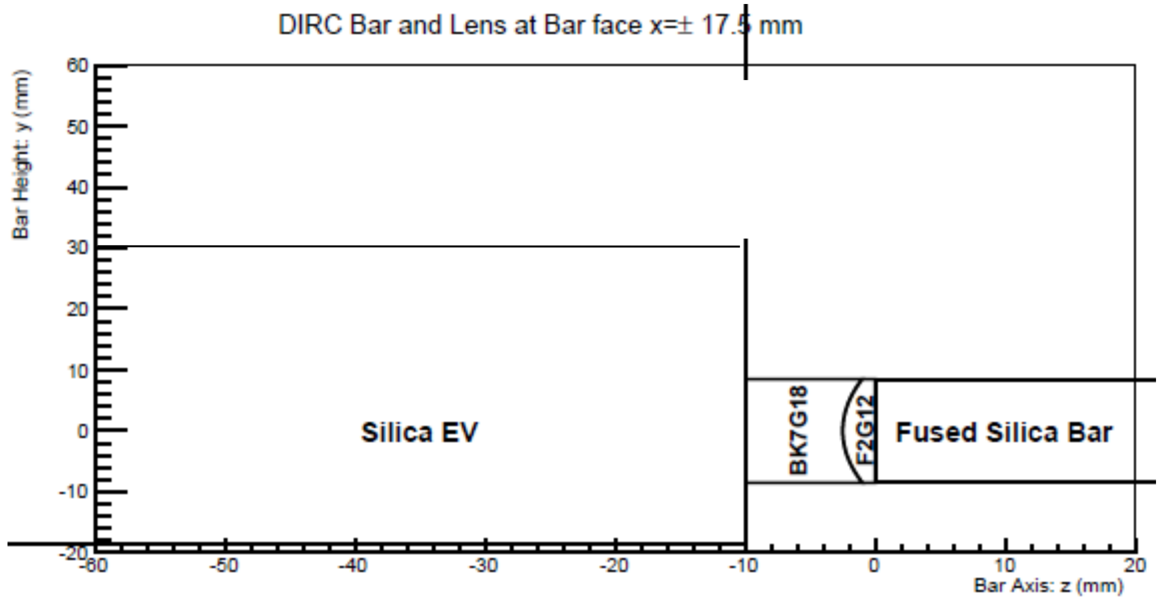
Trapezoid with 30 degree angle
Similar dimensions as for the box

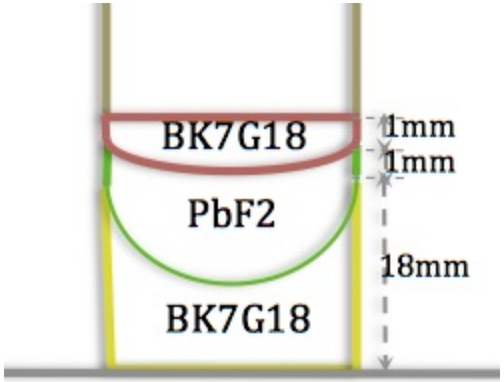


Benchmark EV (box) geometry
30 cm long, 15 cm high, 1 cm step

Lenses with high refractive index (no air gaps)

- Lenses with air gaps cause photon losses around 90°.
- This is addressed through novel lenses with high refractive index, attached without air gaps to both bar and expansion volume.
- A new spherical three-layer lens is now ready and will be tested in-beam soon
- Simulations show that spherical lenses offer significantly better resolution than cylindrical ones, but the two planes are not equally sensitive
- Will an elliptical lens give the best balance between resolution and simple focal plane shape?



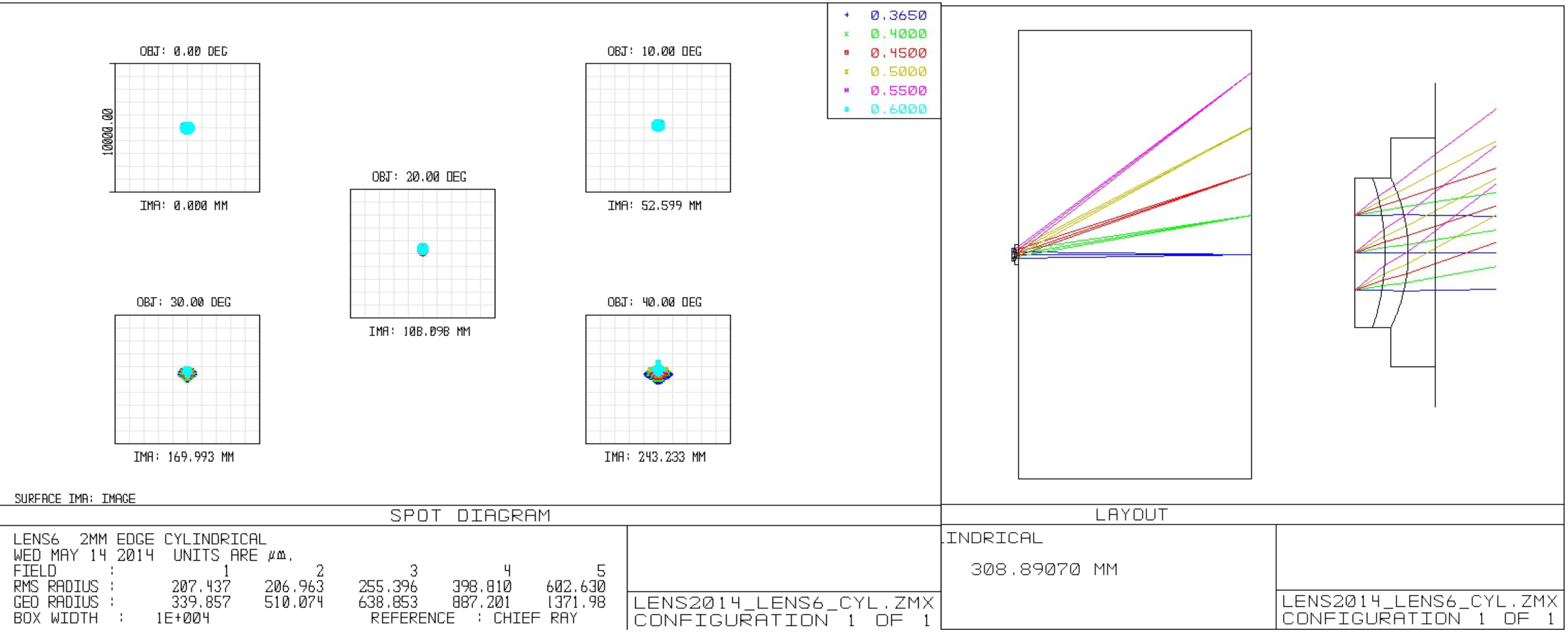


Triple lens
Midplane view

Double lens
Midplane view

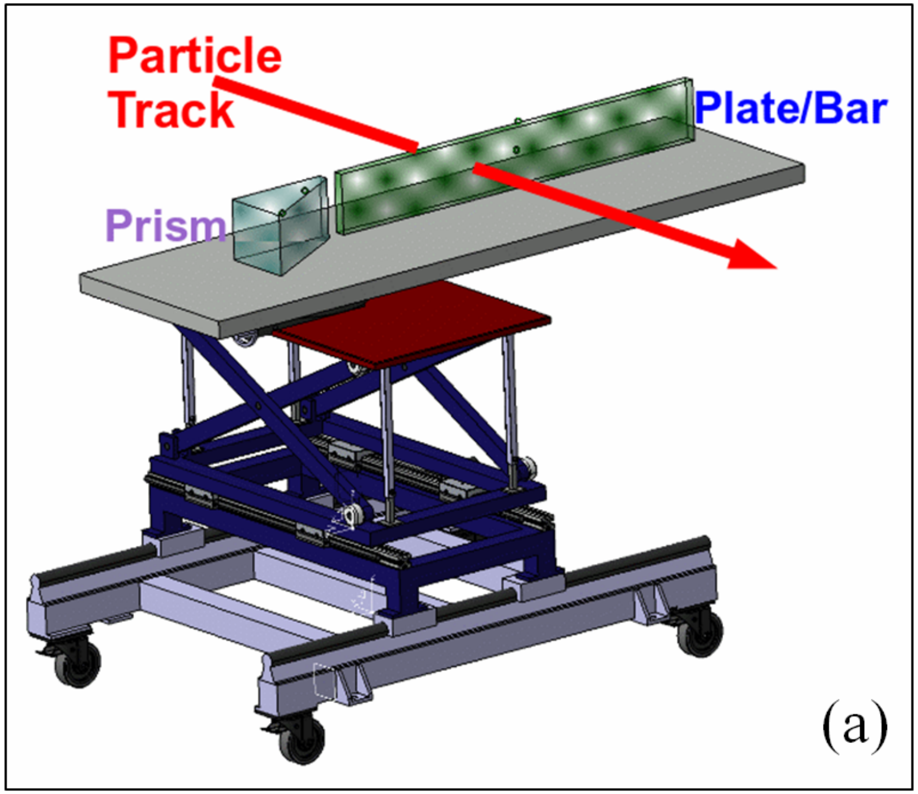
New three-layer lens with high index of refraction

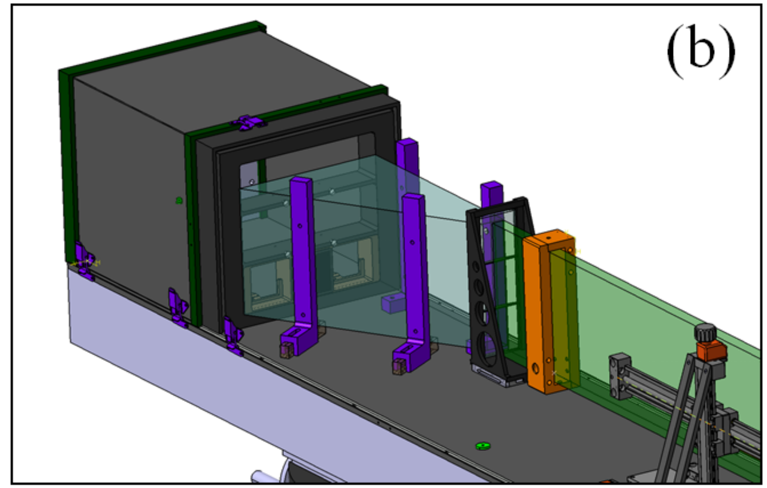
Surf:Type		Comment	Radius		Thickness		Glass	Semi-Diameter		Conic	Par 0(unused)	Par 1(unused)	Par 2(unused)
OBJ	Standard	Object	Infinity		Infinity		SUPRASIL	Infinity		0.000			
*	Standard	SiO2	Infinity		3.339	E	SUPRASIL	8.500	U	0.000			
2*	Standard	Lens12 middle	-27.647	V	2.552	E	LAK33	8.500	U	0.000			
3*	Standard	Lens2 front	-20.052	V	3.000		SUPRASIL	8.500	U	0.000			
4*	Standard		Infinity		300.000		SUPRASIL	13.000	U	0.000			
IMA	Standard	Image	Infinity		-		SUPRASIL	300.000	U	0.000			

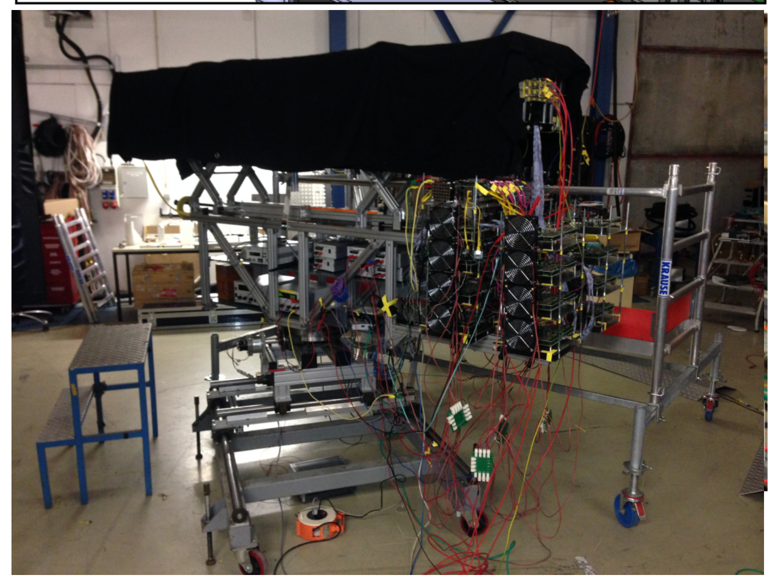


- ZEMAX calculation for spherical three-layer lens designed by C. Schwarz

Test beam setup





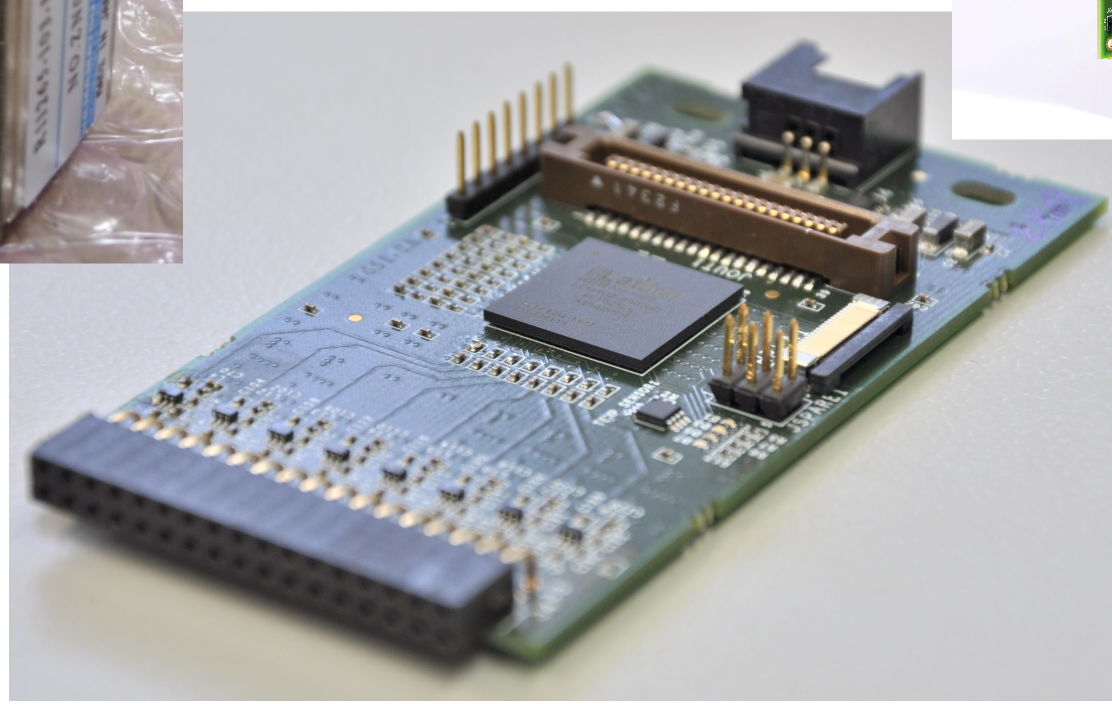


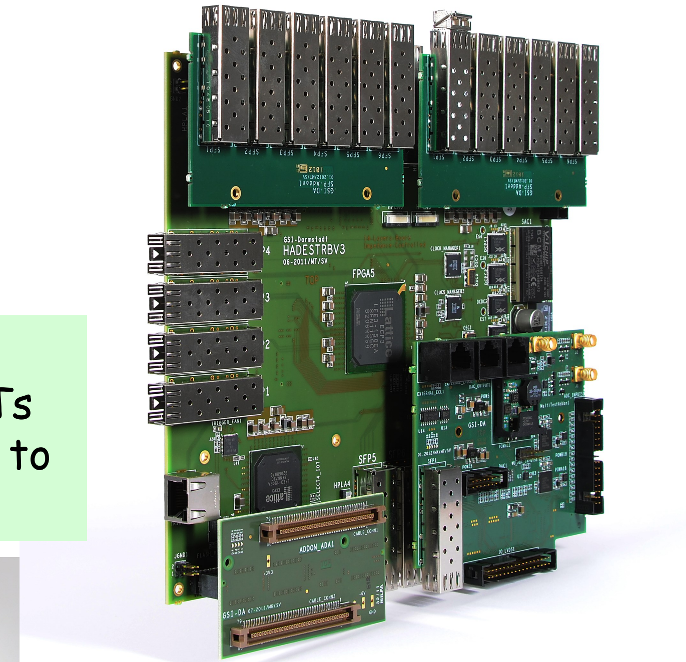
- The EIC DIRC prototype will take full advantage of synergies with PANDA DIRC R&D.
- The goal is to test the new lenses and small-pixel sensors, initially using existing GSI expansion volumes, and later with an EV geometry optimized for the lens focal plane.

Procurements for test at GSI

Hamamatsu R11265-103-64 small-pixel MaPMTs
256 channels total (4 MaPMTs).
Photo taken in transit at JLab

PaDiWa interface card for connecting the procured MaPMTs (via Hamamatsu E11906 sockets) to the TRBv3 DAQ card (right).



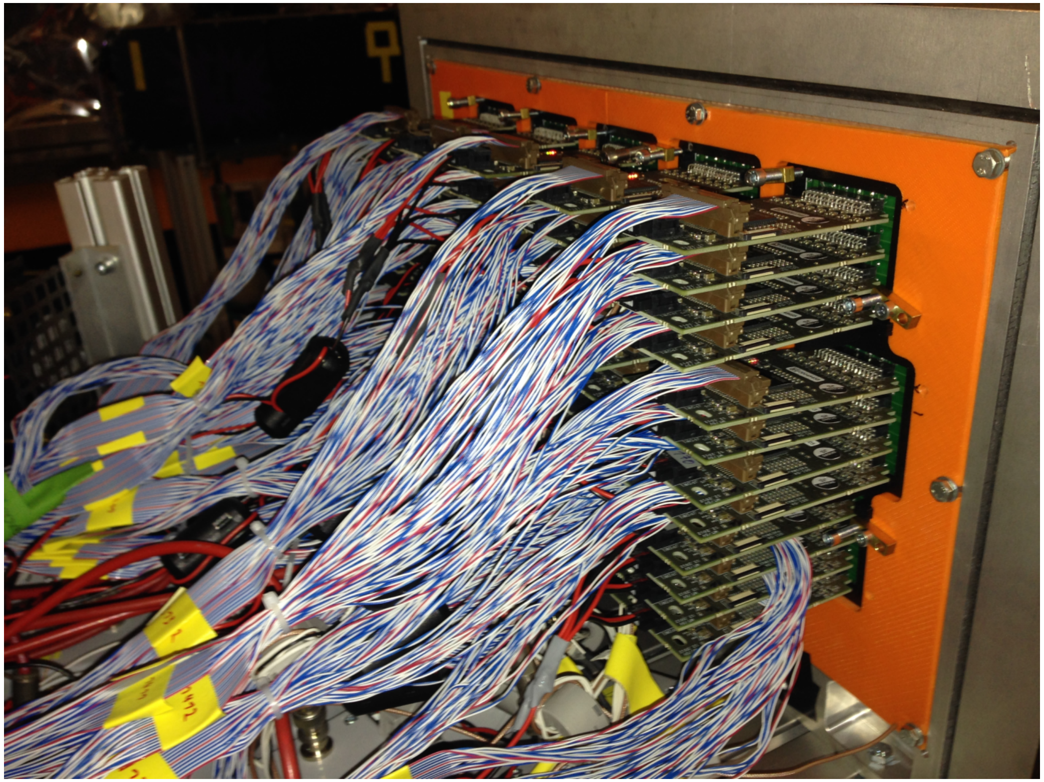


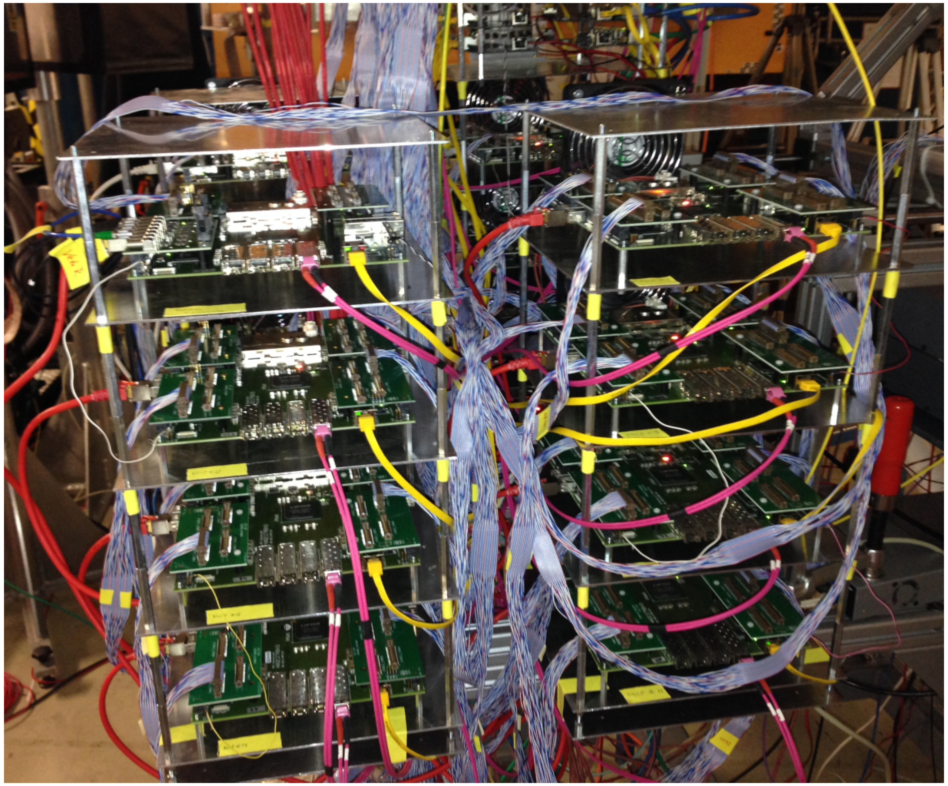
TRBv3 DAQ card
with AddOns

The new three-layer lens for the August test beam is being built by Befort Wetzlar

Readout and DAQ for test beam setup

PaDiWas connected to 3*5 MCP-PMTR array,
ribbon cable connection to TRBs

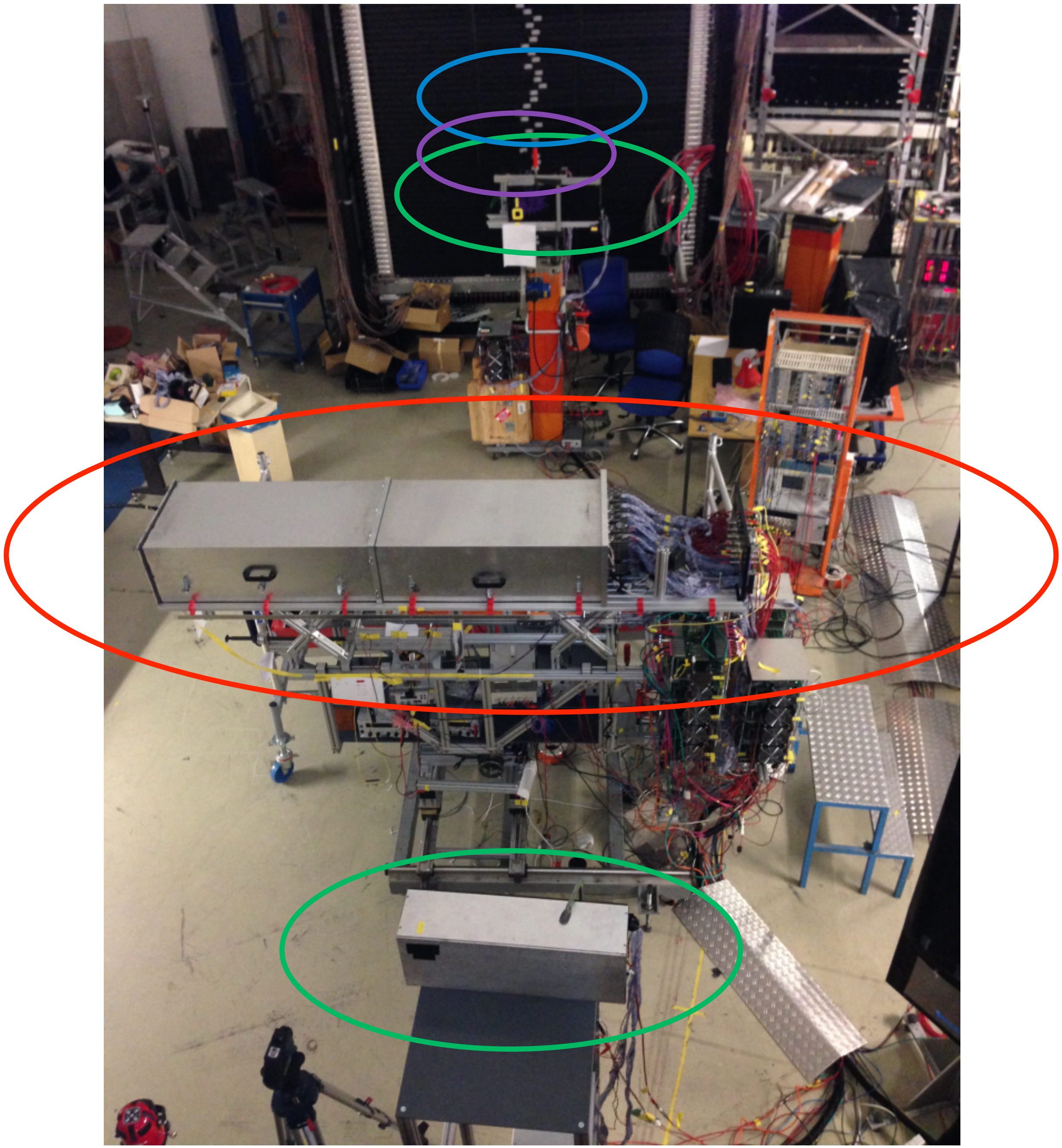




Stack of DAQ TRBs

- The Hamamatsu MaPMTs require special PaDiWa interfact cards since the socket differs from that of the Planacons
- The EIC small-pixel sensors form a complete chain that can be interfaced into the PANDA DAQ

Setup at GSI during the July 2014 beam time



Downstream Trigger Counter

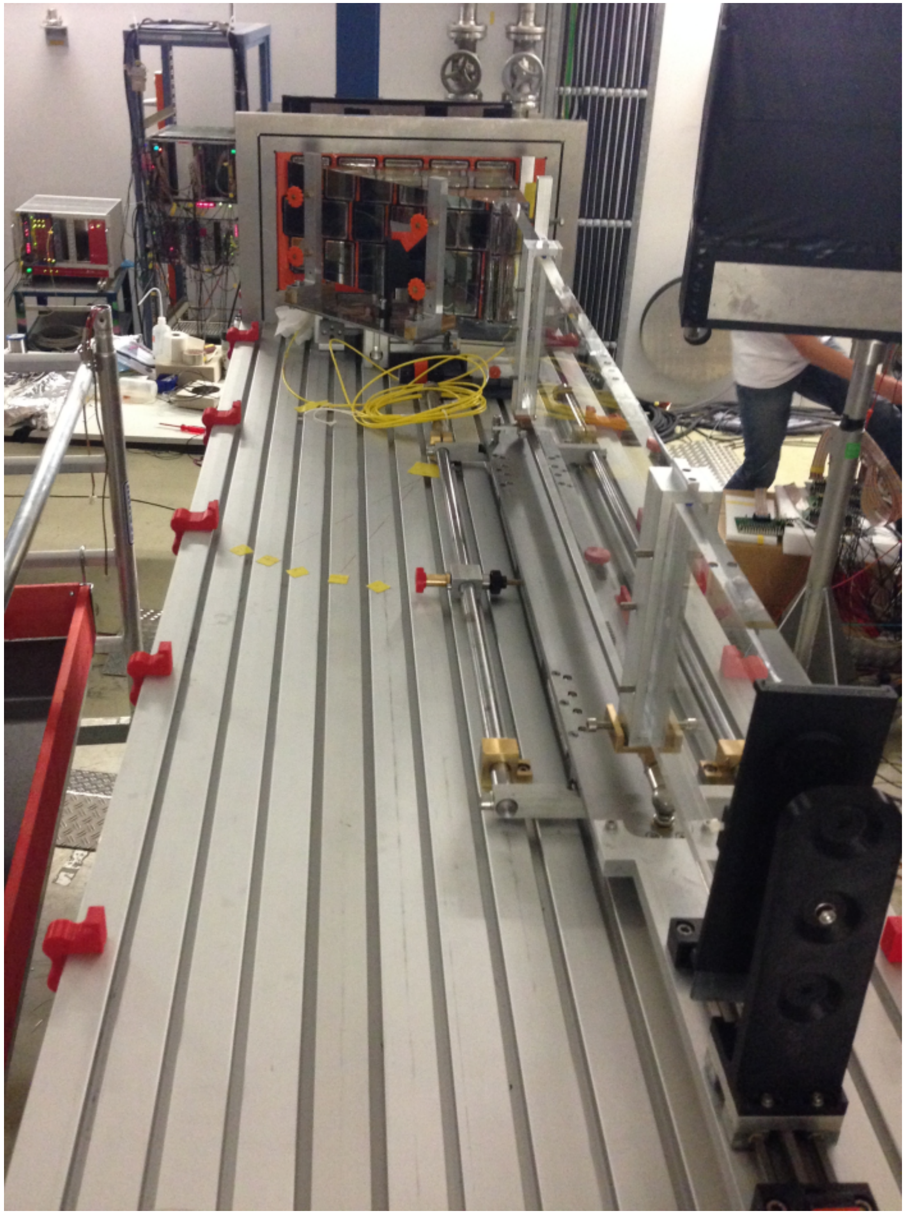
Downstream MCP-TOF Counters

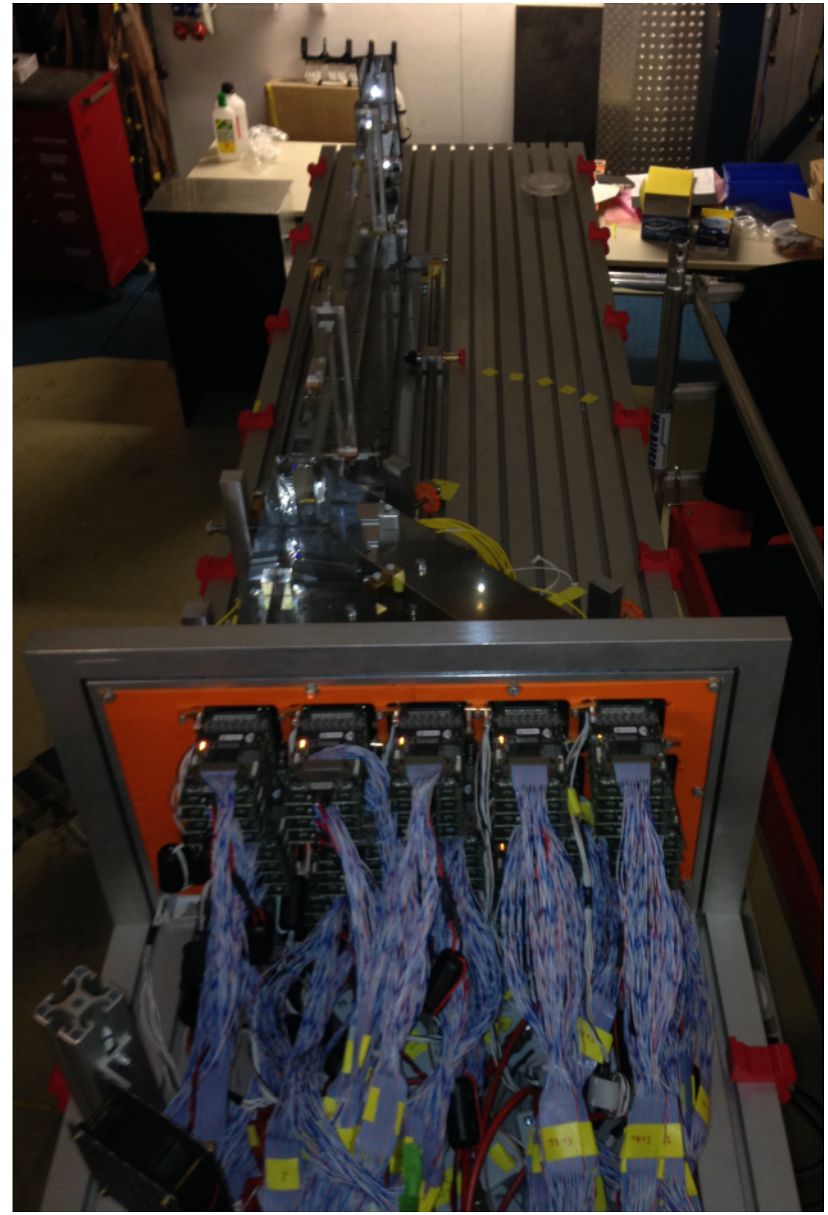
Downstream Fiber Tracker

Barrel DIRC Prototype

Upstream Fiber Tracker

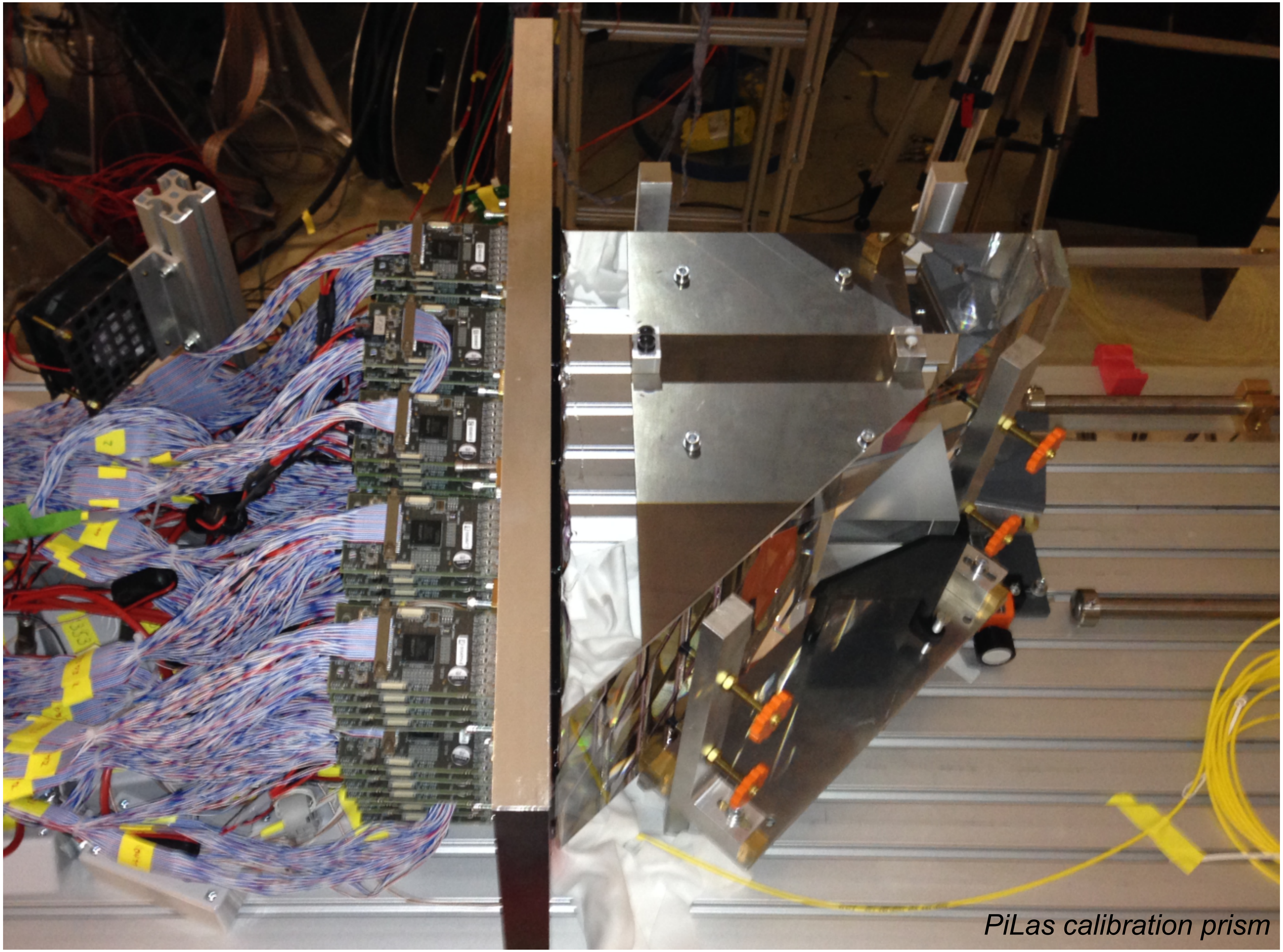
Closeup of current DIRC prototype





DIRC prototype seen from mirror end (left) and from readout end (right)

Fused silica expansion volume and readout

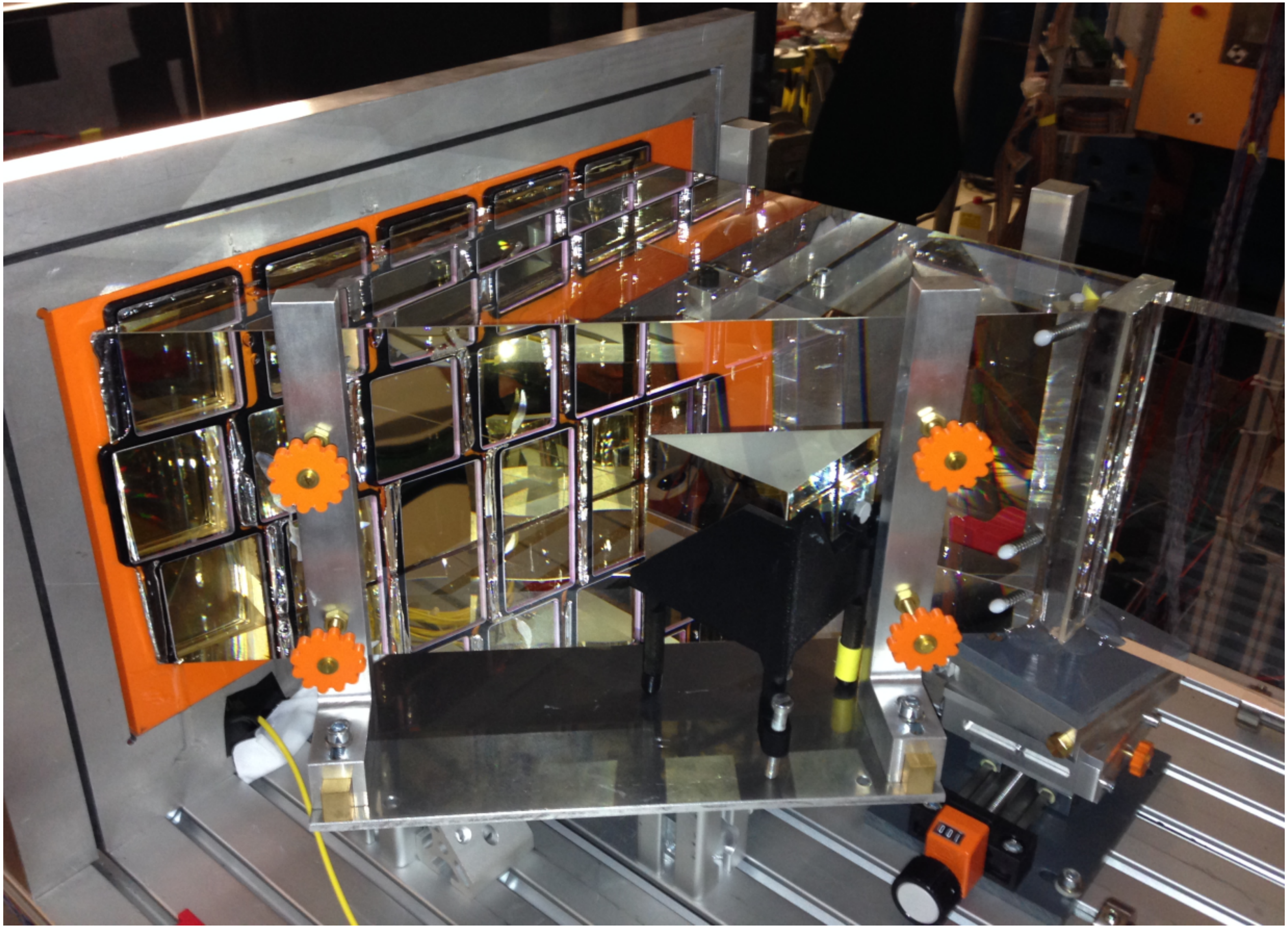


Readout electronics:
PaDiWa boards

MCP-PMTs

Optics: 30 cm long fused silica prism,
lens w/o air gap, radiator bar

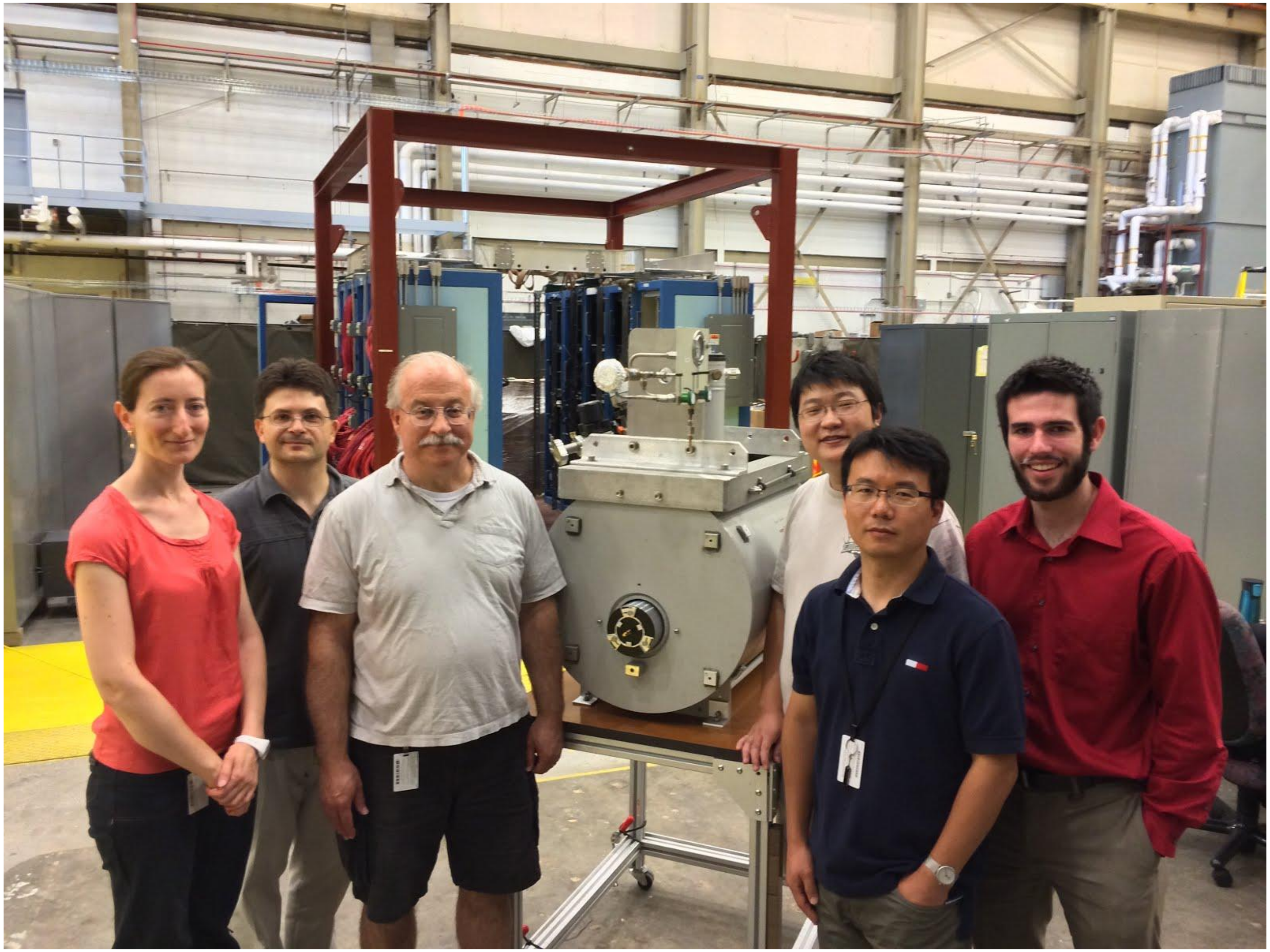
Expansion volume, lens, and MCP-PMTs



MCP-PMTs can be Photonis Planacon or the small-pixel ones procured for the EIC R&D.

(Small PiLas calibration prism in front.)

Tests of photosensors in high magnetic fields

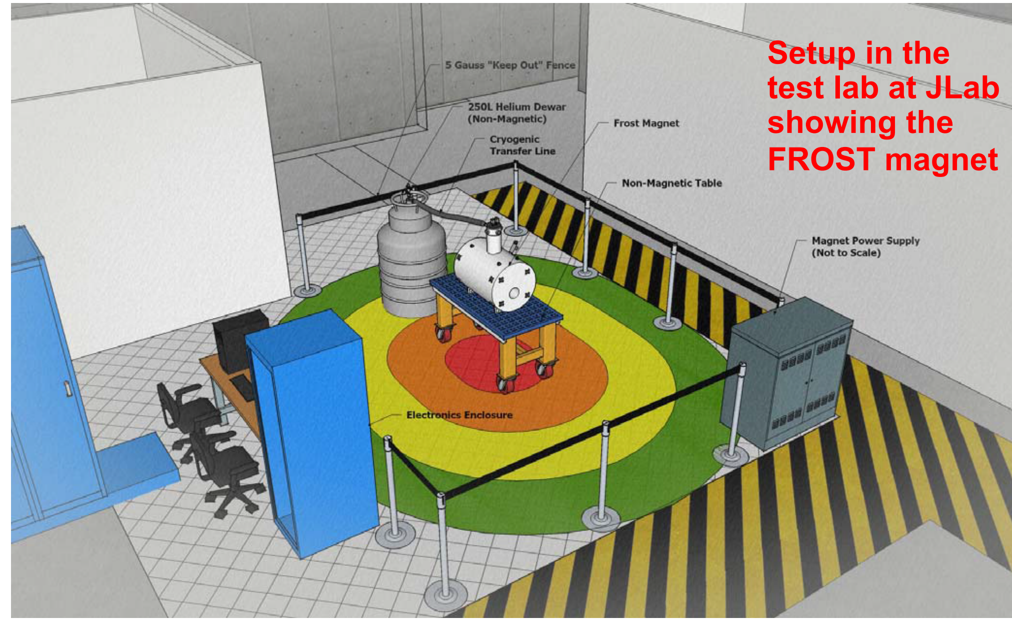


Y. Ilieva (USC), P. Nadel-Turonski (JLab), C. Zorn (JLab), T. Cao (USC), K. Park (ODU), and E. Bringley (USC) in front of the 5T FROST magnet in the permanent test area at JLab. Note the sensor test tube inside the 5” magnet bore.

High-B field – test facility status

Setup complete in permanent area in new test lab at JLab

- All components are in place
- "Warm" tests are in progress
- Magnet cooldown scheduled for end of July, with commissioning early August



Initial tests will measure gain as function of B and angle

- How do pore size, coatings, etc, affect high-field behaviour?
- Angle important as MCP orientation with respect to field may vary in final application
- Timing is generally less affected by B-field, but could be an important follow-up study
- Future measurements could combine effects of radiation damage and magnetic field

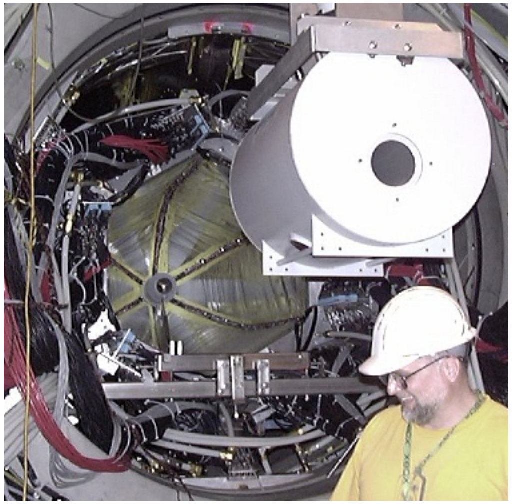
Production runs in years 4 and 5

- Y. Ilieva at University of South Carolina is leading effort
- 1-2 cool runs per year are planned

High-B field – magnets

Initial tests will use FROST magnet

- Two magnets formerly used with CLAS are dedicated for the high-B field test facility – the larger DVCS and smaller FROST solenoids
- Both magnets can reach 5 T, but the FROST one is cheaper to set up and operate (requires less LHe)



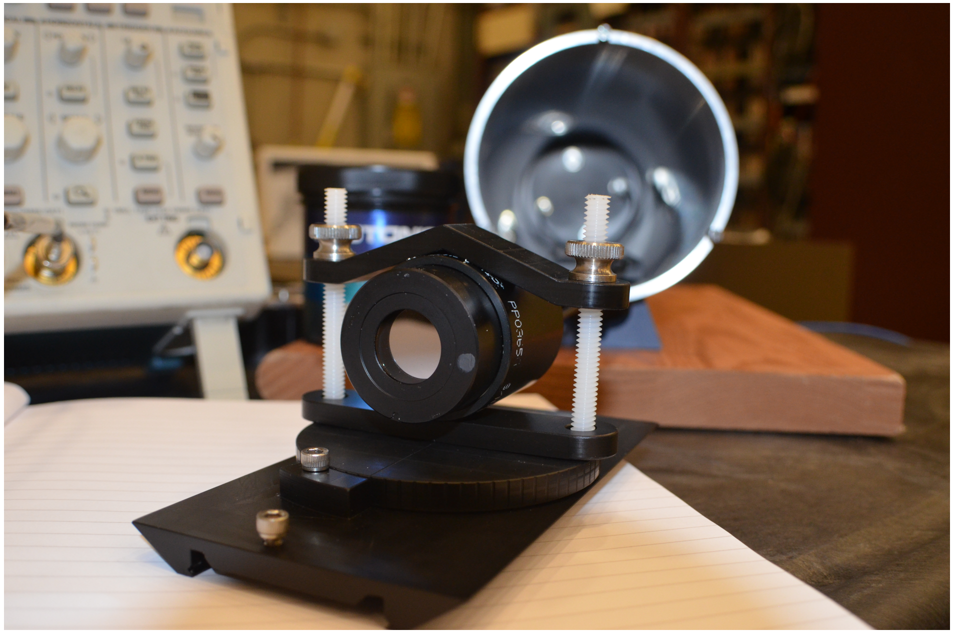
CLAS FROST solenoid
with 5 inch bore

Long-term strategy for facility

- Perform first series of tests using smaller magnet.
- In the future, a larger bore can be needed to accommodate larger sensors (LAPPDs) or provide more space for rotations
- Test boxes have been built for both magnets (C. Zorn)
- Both magnets will be part of the facility and can be used for future measurements as required

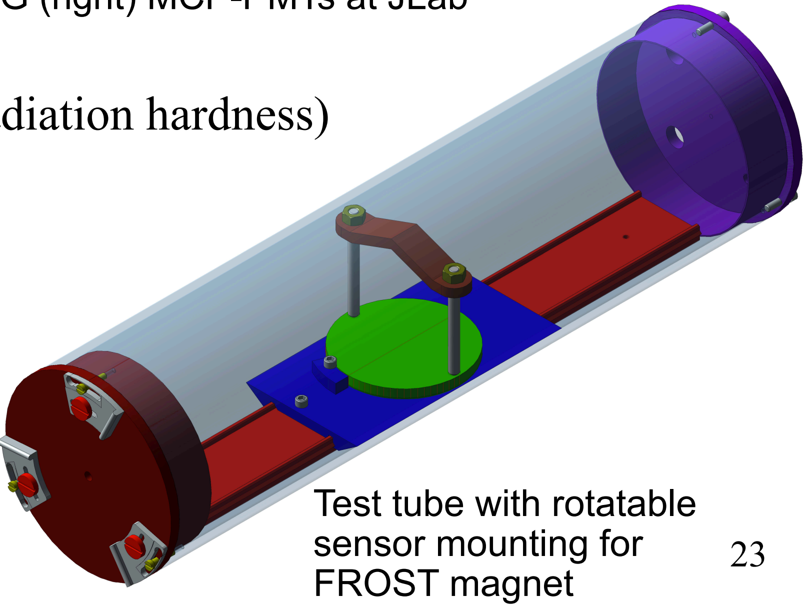
CLAS DVCS solenoid with 9 inch bore

High-B field – sensors for first round of tests



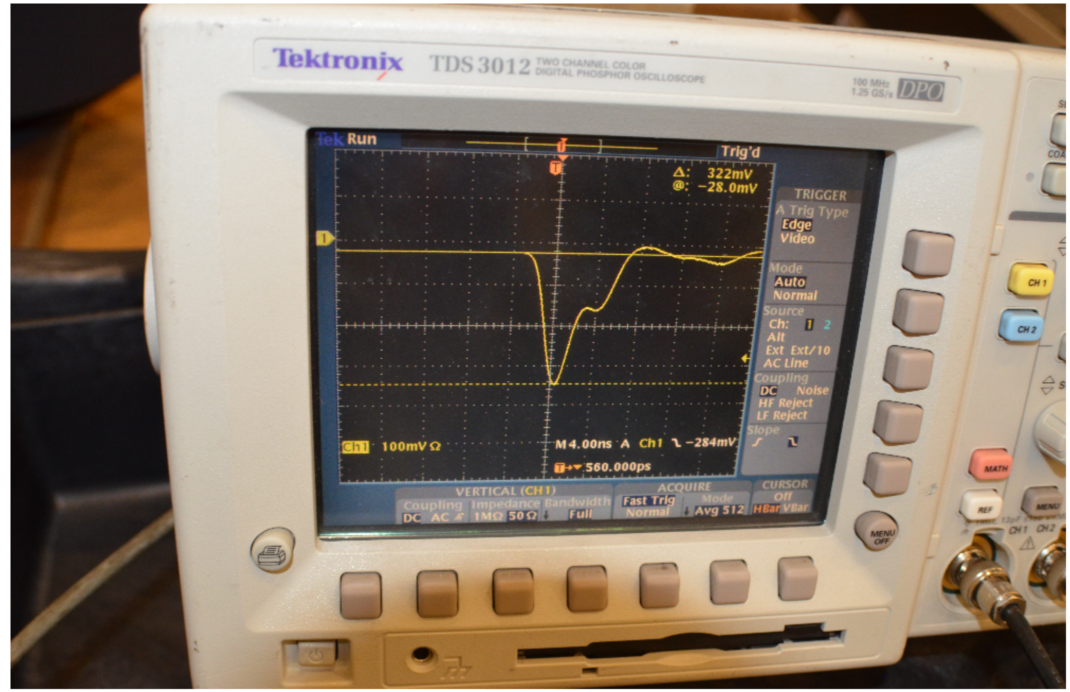
Photonis Planacon XP85012 and XP85112 (left), and round PP0365G (right) MCP-PMTs at JLab

- MCP-PMTs offer good single-photon resolution (and radiation hardness)
  - could become a baseline photosensor for the EIC
- To reduce cost, manufacturers were invited to lend us sensors for testing (only shipping costs)
- Photonis and Photek have already provided five MCP-PMTs with various pore sizes for initial tests
  - Hamamatsu has also shown interest



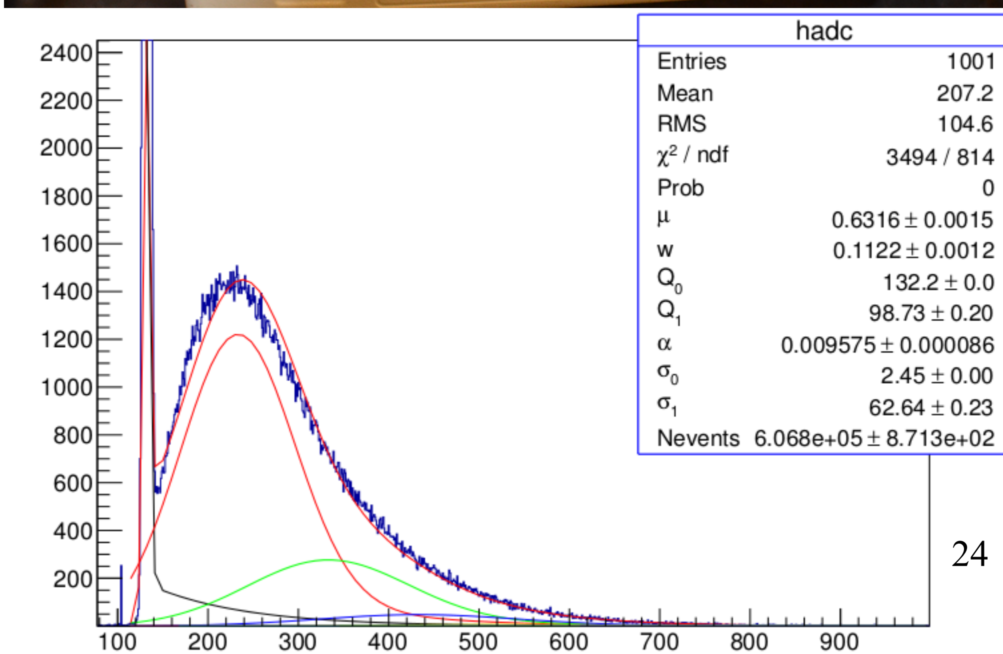
Test tube with rotatable sensor mounting for FROST magnet

High-B field – bench test of MCP-PMTs

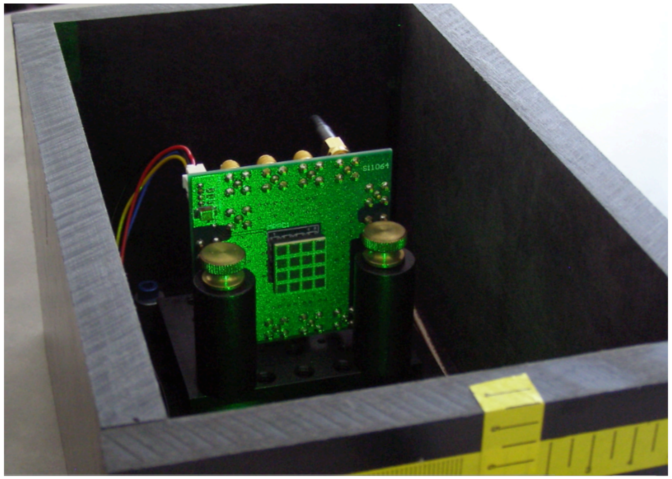


- “Warm” measurements of the MCP-PMTs, on the scope and using JLab 12 GeV flash ADCs and DAQ (CODA).

- Fits to voltage-sampled spectra taken for the PP0365G with a x200 pre-amplifier show a gain of 3×10^6.

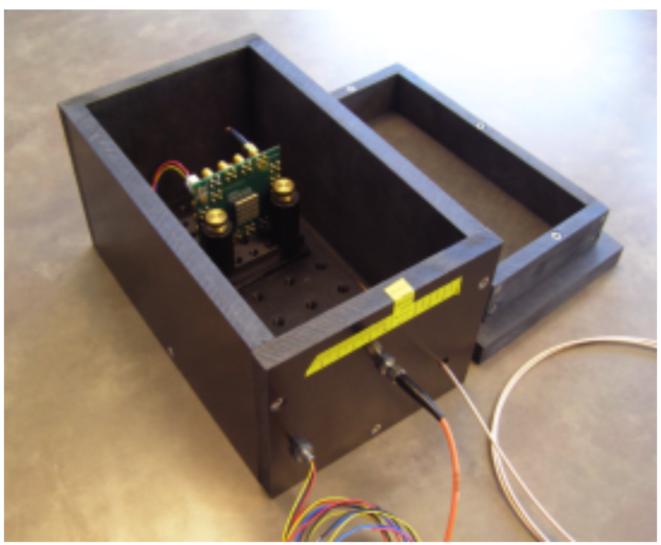


High-B field – planned sensor tests



Non-magnetic dark box with pulsed LED for the DVCS solenoid – note the GlueX SiPM (Hamamatsu S11064-050P(X))

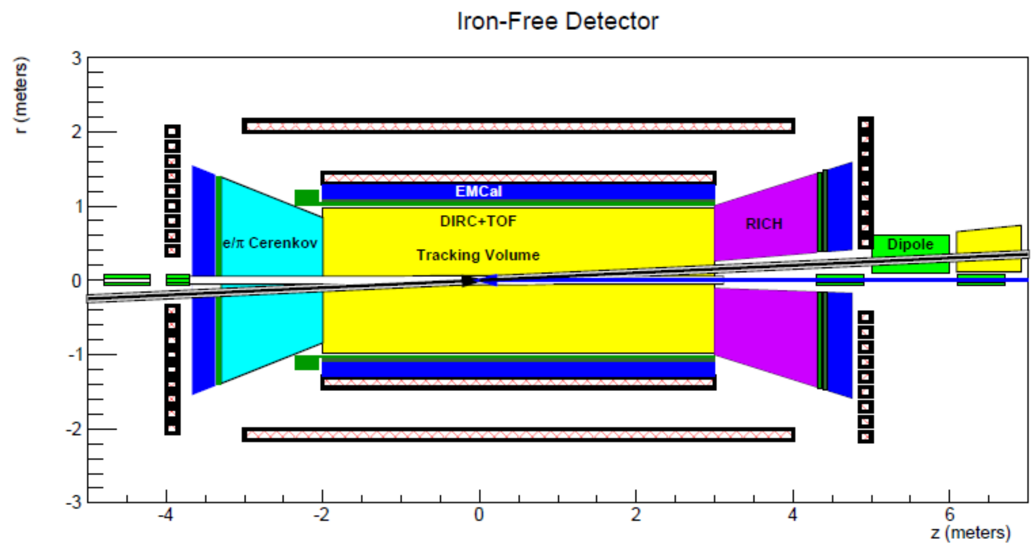
Katod single-anode MCP-PMTs. Two have been ordered, with 3 and 5 μm pore size, respectively



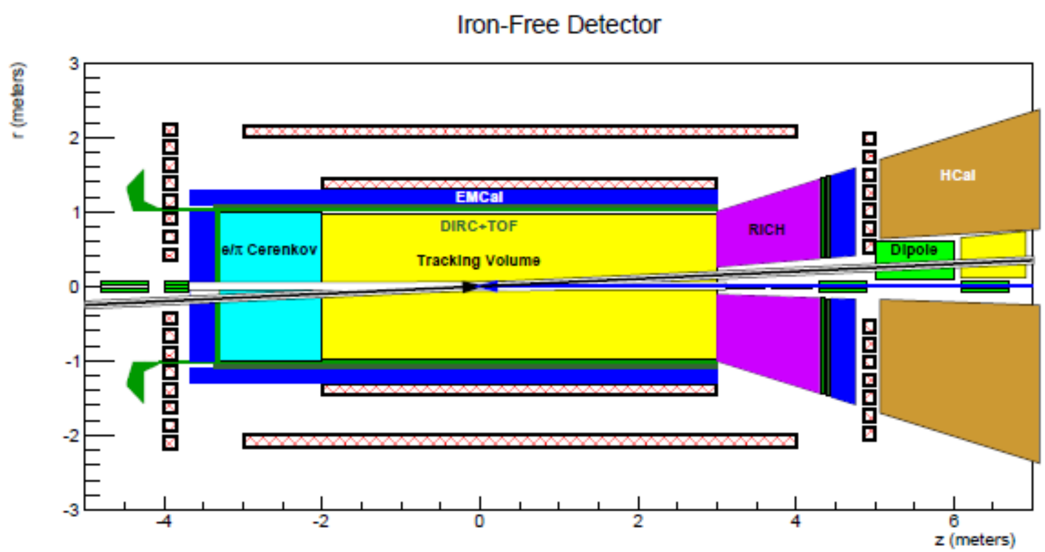
- Future tests will include the procured but delayed Russian Katod MCP-PMTs with very small pore sizes

- SiPMs can be tested in either the FROST or DVCS magnet (test box shown).
    - Impact of radiation damage can be studied (irradiated SiPMs are available).

Possible layouts with internal and external EV

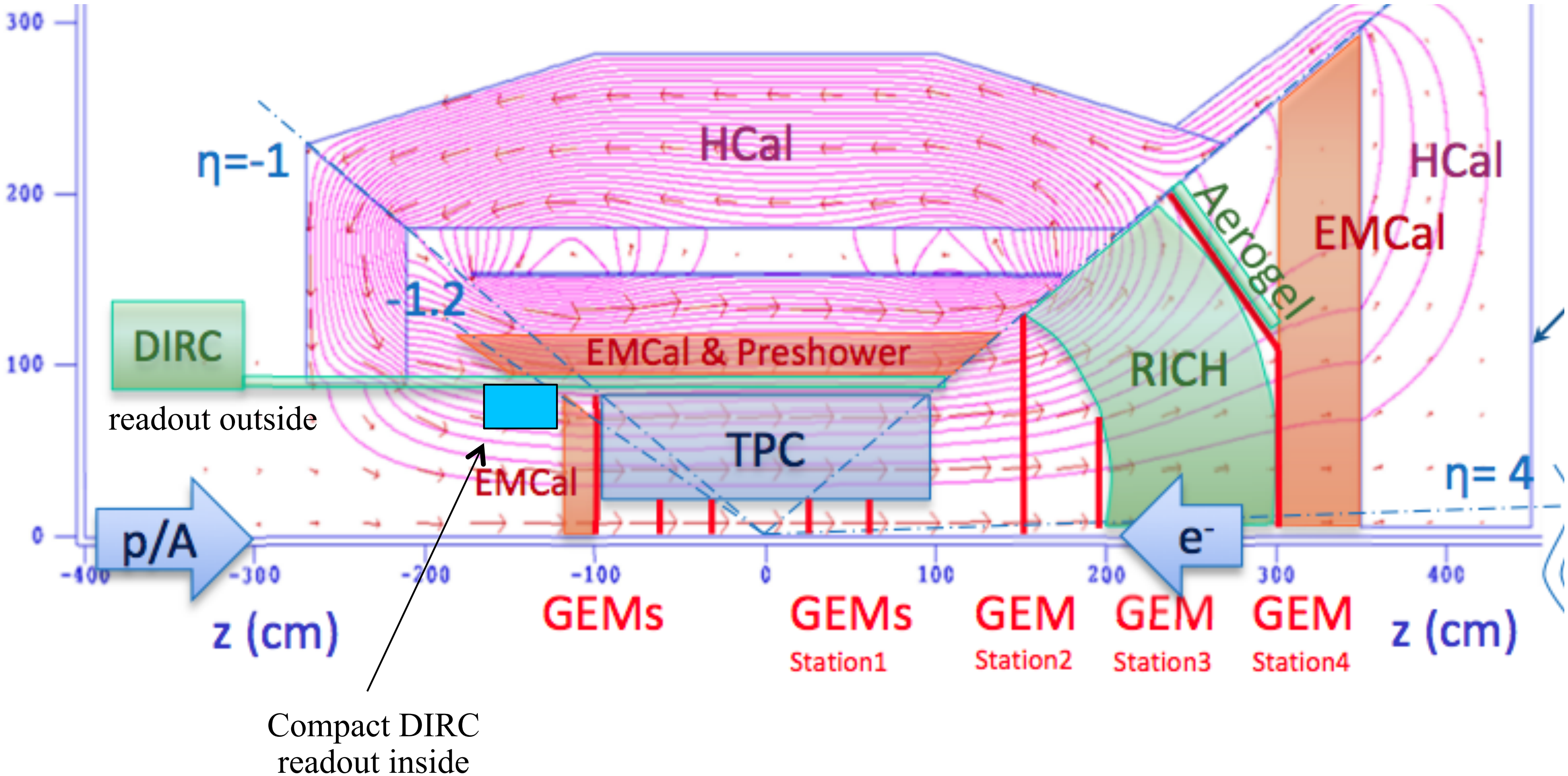


- A DIRC-based PID solution for the central detector can have the EV placed inside or outside of the detector.
- An internal solution requires a compact EV



- The DIRC bars/plates would be quite long if the EV was outside.
- Need to evaluate the impact of long bars/plates on endcap design
- Caveat: flux return using endcap coil walls instead of iron could offer variations on the theme

Possible layouts with internal and external EV



- An EIC detector evolved from a new PHENIX, based on the BaBar solenoid would provide a lot of semi-internal space for the DIRC readout
- Question: how specific should integration studies be?

Meetings and travel last year funded by the grant

Yearly collaboration meeting at JLab in March, 2014

- Full participation – and new GSI collaborator

Postdoc recruitment

- New postdoc (from GSI) hired in May, 2014

Invited talk at DIRC 2013 specifically on this DIRC R&D project

- Also mentioned at many conferences not funded by grant

Travel to BNL for meetings with the advisory committee

Travel for University of South Carolina for setting up test facility

- Paid both from the JLab and USC travel funds

Budget summary

Budget	Year 1	Year 2	Year 3	Year 4	Year 5	*Total*
Postdoc (50%)	$53,290	$54,000	$55,200	$52,305	$55,147	*$269,942*
Students	$8,300	$13,764	$13,764	$13,784	$13,764	*$63,356*
Hardware	$41,970	$58,630	$24,000	$30,000	$36,000	*$190,600*
Travel	$11,440	$13,606	$22,036	$18,931	$10,089	*$76,102*
Total	*$115,000*	*$140,000*	*$115,000*	*$115,000*	*$115,000*	*$600,000*

Budget	Year 1	Year 2	Year 3	Year 4	Year 5	*Total*
Old Dominion University (ODU)	$53,290	$54,000	$55,200	$52,305	$55,147	*$269,942*
Catholic University of America (CUA)	$9,800	$8,300	$8,300	$8,300	$8,300	*$43,000*
University of South Carolina (USC)		$7,606	$12,646	$12,646	$7,606	*$40,504*
JLab and GSI (through MoU)	$51,910	$70,094	$38,854	$41,749	43,947	*$246,554*
Total	*$115,000*	*$140,000*	*$115,000*	*$115,000*	*$115,000*	*$600,000*

- Postdoc salary matched by ODU funds (50%)
- Synergies with GSI: hardware for beam tests and optics studies
- In-kind contributions from JLab: two 5T solenoids, lab space, etc, for high-B test facility
- Free sensor loans (to date) from Photonis and Photek: 5 MCP-PMTs (~ $10k each)
- *Note that in Year 2 this proposal merged with the sensor radiation hardness one (C. Zorn)*

Primary responsibilities

1. Simulations of DIRC performance and design of prototype

- Old Dominon University

2. Lens and expansion volume prototype construction and testing

- GSI Helmholtzzentrum für Schwerionenforschung

3. Sensor tests in high magnetic fields

- University of South Carolina and Jefferson Lab

4. Detector integration

- Catholic University of America

Note: **The proposal is a collaborative effort and most institutions will contribute to more than one of the areas above regardless of their primary responsibility**

Summary

Simulations

- New, experienced postdoc (G. Kalicy) hired at ODU
- Additional collaborators form GSI joined the proposal and general effort
- The very encouraging proof-of-concept results are being tested
  - Independent ray-tracing studies and full GEANT4 implementation
- Next thing is to continue optimizing the lens and EV configurations as in proposal
  - This includes mirror-based configurations that could be "outside" of the detector

Hardware and beam tests

- Development and procurement is on track
- Beam tests at GSI in 2014, and CERN in 2015
  - Final test at CERN in 2016?

High-B field sensor testing facility

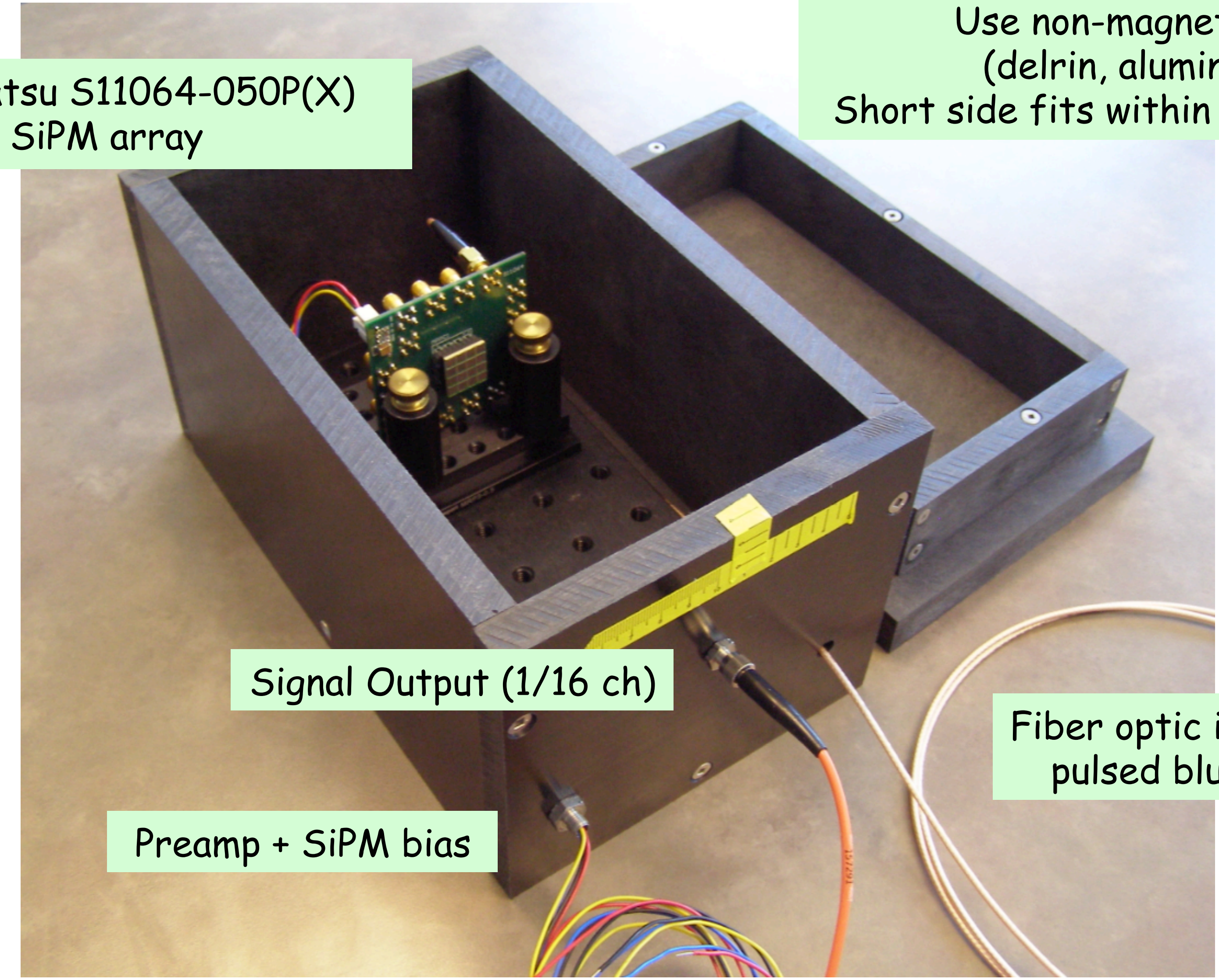
- Facility is now ready to run – liquid helium is on the way!
  - Slight delay due to late availability of year 3 funding will not affect overall schedule
- Large and growing user involvement
- Sensor loans (Photonis, Photek) give an economical way to leverage results
  - Delays in delivery of Katod MCP-PMTs will not have a major impact on schedule

Backup

High-B sensor test facility – dark box

1st version of dark box
Use non-magnetic materials
(delrin, aluminum, brass)
Short side fits within 22 cm magnet bore

Hamamatsu S11064-050P(X)
SiPM array



Signal Output (1/16 ch)

Fiber optic input for
pulsed blue LED

Preamp + SiPM bias

Design choices

1. Focusing

- Proximity focusing (BaBar)
- Mirror on the side opposite of readout (Belle)
- Mirror on the side of the readout (SuperB)
- Lenses (PANDA)

2. Expansion volume and sensors

- Inside detector volume
- Outside of endcap (and iron or equivalent)

3. Radiator bars

- Boxes of narrow bars (BaBar)
- Plates = wide bars (Belle)

Design strategies

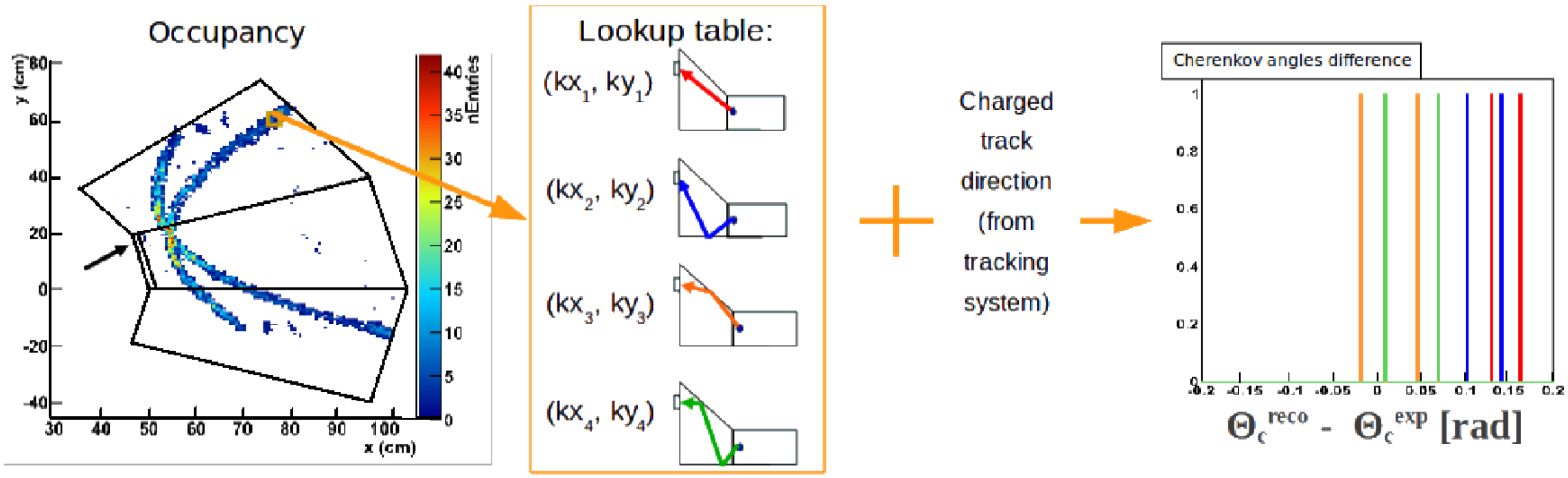
1. Expansion volume inside detector

- Narrow bars of moderate length (4-5 m)
  - Reconstruction well understood
  - Good azimuthal segmentation - can handle high multiplicity events
- Compact expansion volume important (fused silica)
  - Lens focusing primary choice – concept benefits from PANDA R&D
- Sensor challenges
  - High magnetic fields (low-noise SiPMs or MCP-PMTs with small pore size?)
  - Radiation? (EV in „quiet" corner)

2. Expansion volume outside detector endcap and iron

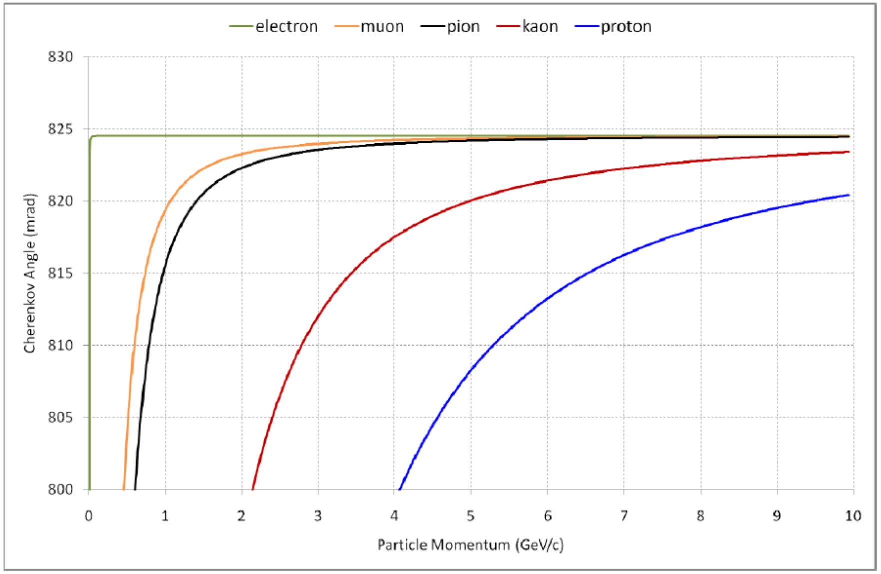
- Long bars – wide plates preferable in order to reduce number of reflections
  - Lower tolerances and potentially lower total cost
  - Requires new reconstruction methods – synergies with PANDA R&D
  - Azimuthal segmentation requirements need to be studied
- Fewer constraints on EVsize and orientation – can be radially large
  - Mirror focusing similar to FDIRC for SuperB?
- Sensors – easier access and moderate magnetic fields (MCP-PMTs?)
- Major impact on endcap detectors – needs to be studied!

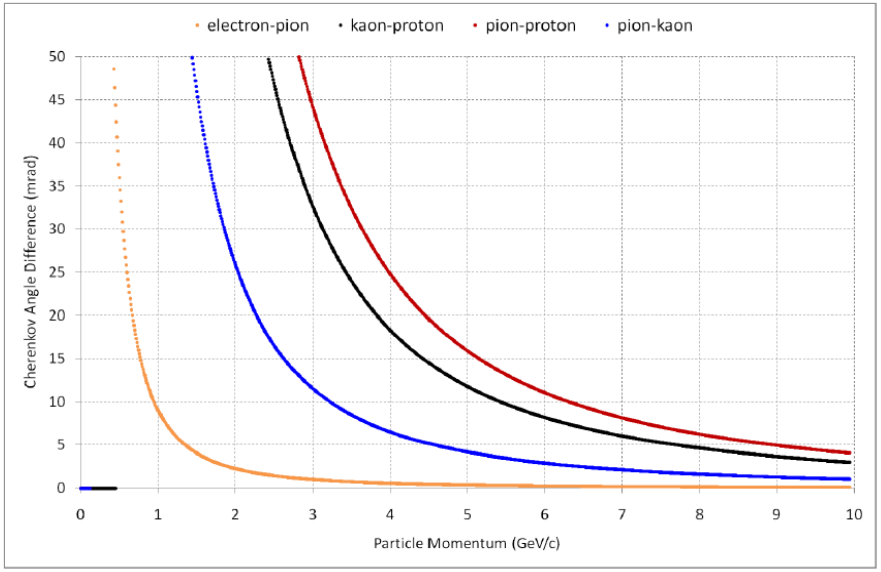
Event reconstruction

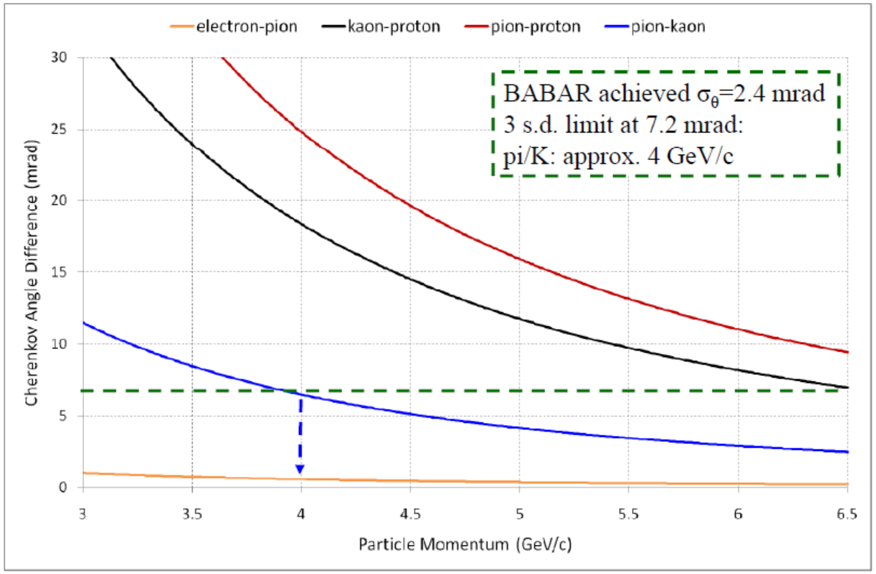


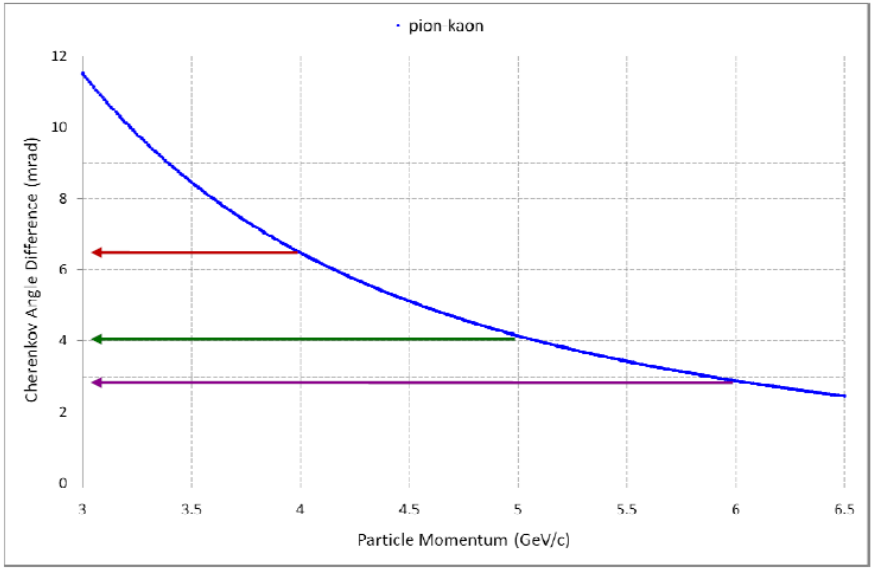
- For design purposes the main goal is to establish a figure of merit
- Explicitly reconstruct the single-photon θ_c resolution and photon yield
- Currently the algorithm uses a spatial lookup table (generated through simulation) combined with cuts on the time of propagation
  - Will be extended to include time explicitly in lookup table!

Momentum coverage and θ_c resolution



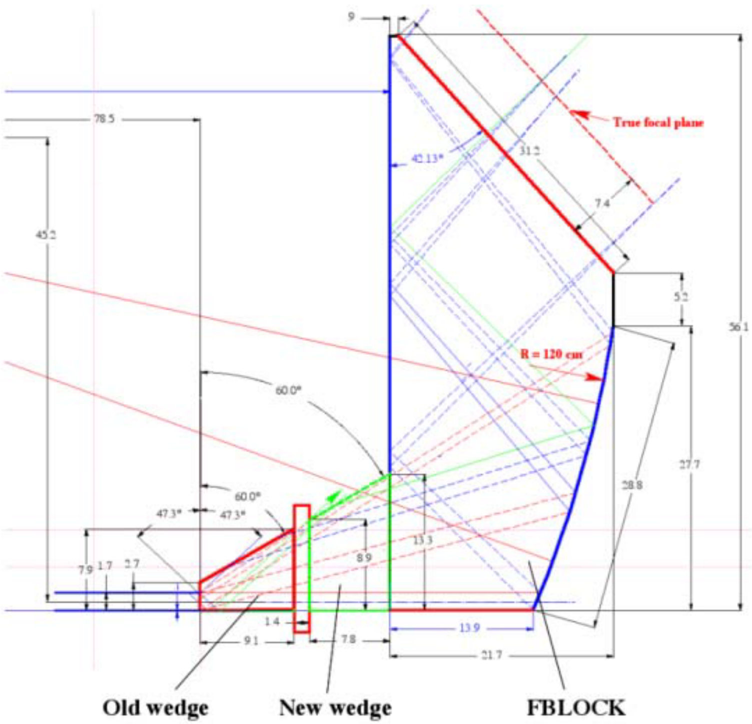




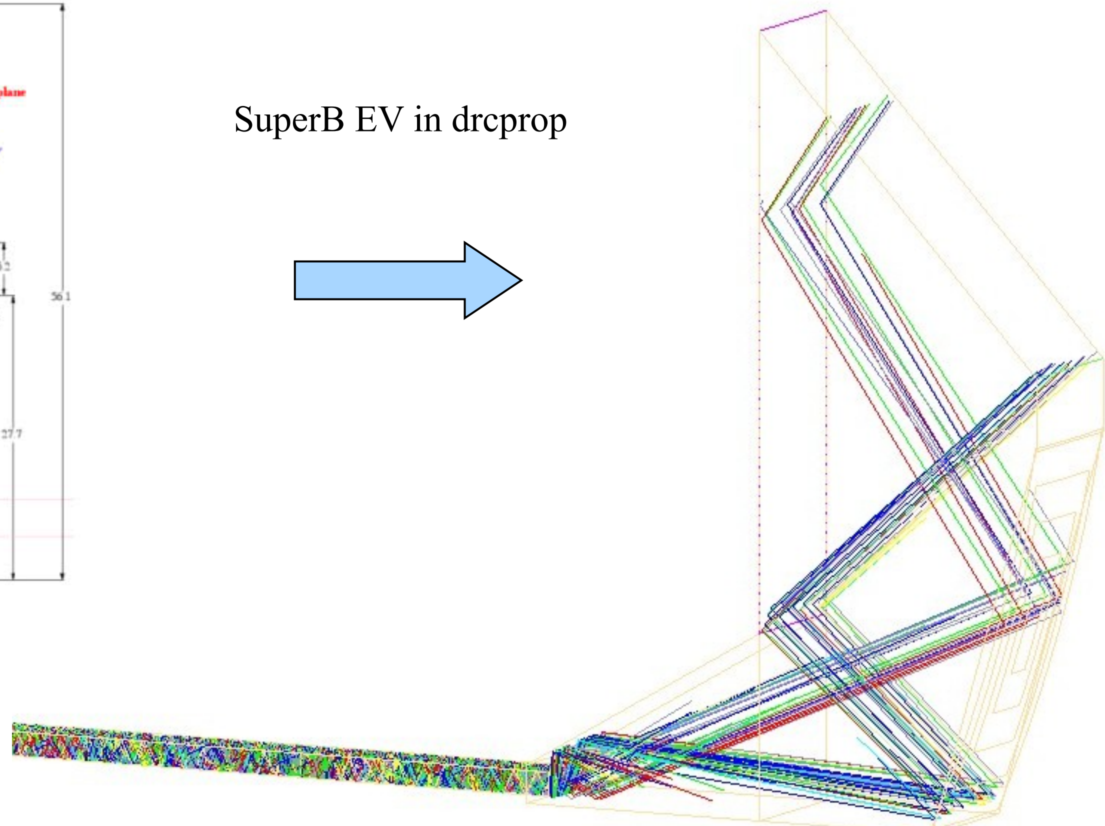


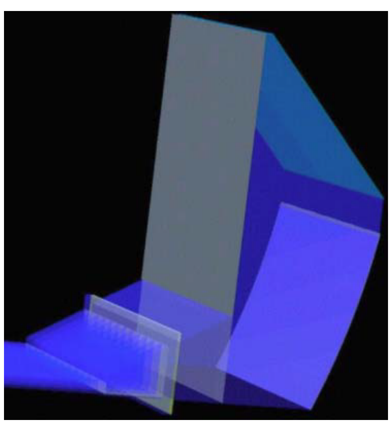
- Extending π/K separation from 4 to 6 GeV/c requires $\sigma_\theta \sim 1$ mrad (vs 2.4 in BaBar – a 58% reduction).

Focusing-mirror optics implemented in drcprop



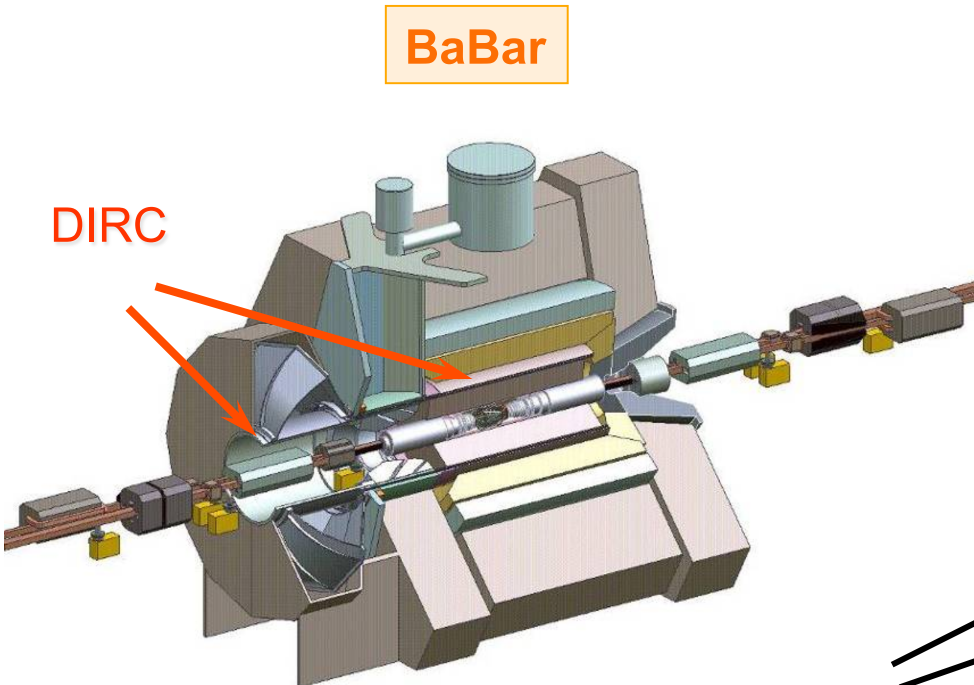
SuperB EV in drcprop

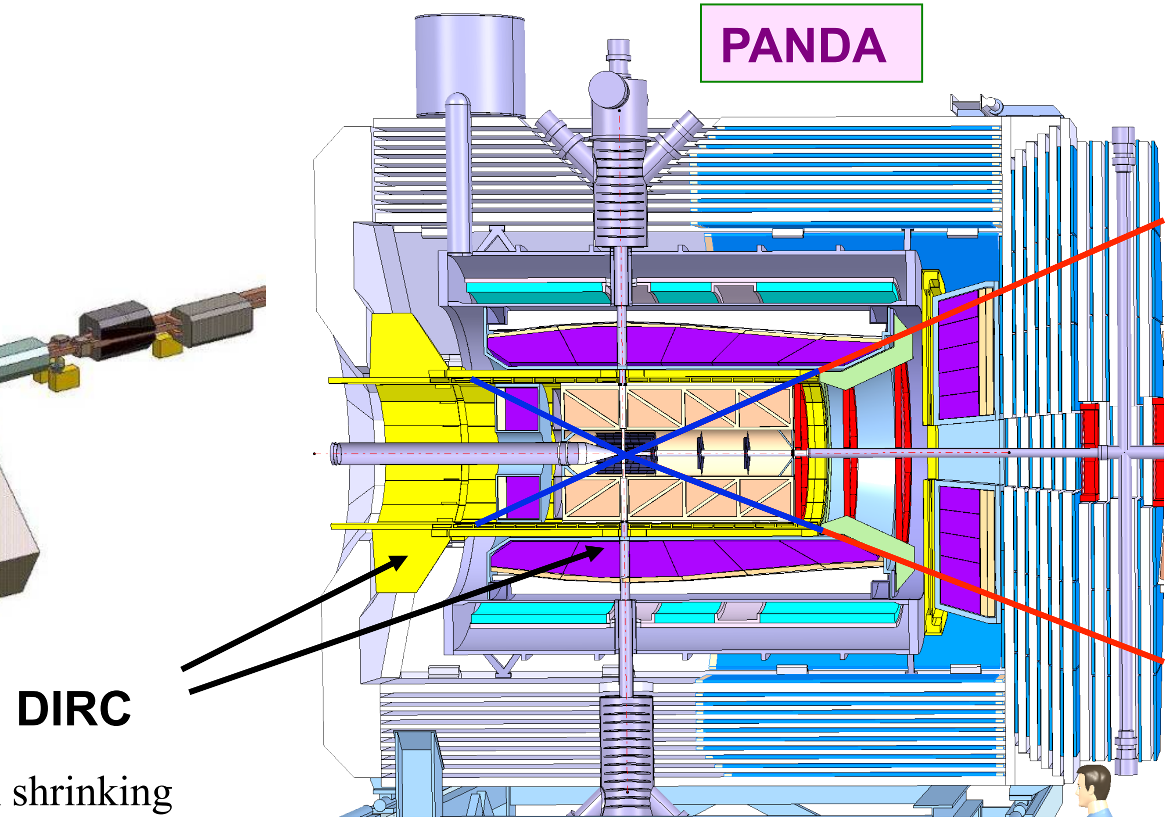




- SuperB mirror optics have been implemented in drcprop
- Will be modified to fit EIC requirements

DIRC "camera" (expansion volume + sensors)





- Expansion volumes (EV) have been shrinking
  - BaBar: 1.2 m long tank with 6000 liters of water
  - PANDA: 30 cm long, 30 cm high EV of fused silica (or with mineral oil)
  - SuperB: 22 cm long, 56 cm high EV of fused silica

- Due to space constraints, the Belle II Time Of Propagation (TOP) DIRC sacrifices spatial resolution (originally also only in one dimension) for compactness of the expansion volume (10 x 10 cm^2).
  - Difficult to push performance using time only, in particular for long DIRC bars